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The Editor will be pleased to receive advance notes on research results for publication in the Journal. Such notes need to be no more than 200–300 words in length.

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THE EFFECT ON THE SOIL OF THE COMPONENTS AND MANAGEMENT OF A LEY

ARTHUR TROUGHTON

Welsh Plant Breeding Station, Aberystwyth

The effect of four grasses, and four methods of utilizing the herbage, on the root weight, the proportion of organic matter in the soil and the water-stability of the soil aggregates was measured over a period of three years. The grass species in the sward had a greater effect upon the measurements than had the methods of management. Of the grass species, *Lolium perenne* produced the greatest root weight and highest percentage of organic matter in the soil.

INTRODUCTION

The value of a ley for improving soil fertility during an arable rotation is well known (3). The grass and legume components of a sward play their part in this improvement, the legumes by increasing the nitrogen status and the grasses by improving the physical structure of the soil; both contribute to the organic matter of the soil.

This investigation is concerned only with the effect of grasses on the organic matter and physical structure of the soil. Four species of widely differing growth habit were studied, and the herbage they produced was utilized in four ways. Grasses affect the soil presumably through the roots; therefore the weight of roots was determined concurrently with the other measurements taken.

MATERIALS AND METHODS

The experiment was conducted on a heavy clay soil in a field near Aberystwyth situated in a wet, sheltered valley, 345 ft. above sea level. The field had been in grass from 1937 until it was ploughed in 1950. After one year's fallow the experimental plots were sown in May 1951. Four species, *Lolium perenne* S101, *Dactylis glomerata* S26, each at 24 lb./acre, *Agrostis tenuis* (New Zealand) at 12 lb./acre and *Festuca rubra* S59 at 30 lb./acre, were sown in eight separate plots 10 yd. × 15 yd. *Trifolium repens* S184 was sown with each species but did not survive a dressing of selective weed killer applied five months after sowing. Each year the plots received the equivalent of 4 cwt./acre of complete fertilizer in spring, and a dressing of selective weed killer and 2 cwt./acre of a nitrogenous fertilizer in the summer.

The plots were grazed as one unit in August 1951. Subsequently each plot was managed as a separate unit. Plots of each species were subjected to 4 methods of management, so that every combination of species and management possible occurred twice in the 32 plots. The plots were arranged in blocks of 4, in which every species and management occurred once. In the analysis of variance, part of the interaction species × management was confounded with the effect of the blocks.

The 4 management methods used during the grazing seasons of 1952 and 1953 were:

Grazed moderately in spring, summer and autumn, i.e., from April to October. Sheep grazed the plots every time there was an adequate amount of herbage.

Grazed hard in spring, moderately in summer and autumn. Grazed hard with sheep from the beginning of April until mid-June, then moderately for the remainder of the season.

Grazed hard in autumn, moderately in the spring and summer. Grazed hard with sheep, beginning in mid-August and continuing until the end of the grazing season.

Cut for hay and aftermath. This management represented the minimum defoliation consistent with the prevention of the accumulation of dead herbage.

During 1954 all the plots were cut for hay and later grazed.

TABLE 1. Effect of botanical composition of the sward on root weight, percentage of organic carbon and percentage of water-stable aggregates

	Lolium perenne	*Festuca rubra*	*Agrostis tenuis*	*Dactylis glomerata*	L.S.D.
Weight of roots (lb./acre)					
0–3 in.	10,700	10,200	9,300	9,200	1,020
3–6 in.	5,500	4,400	4,500	4,500	600
6–9 in.	1,500	1,300	1,300	1,300	n.s.
0–9 in.	17,700	15,900	15,100	15,000	1,930
Percentage of organic carbon					
0–3 in.	5·3	4·8	4·7	4·9	0·3
3–6 in.	4·6	4·2	4·4	4·0	0·4
6–9 in.	2·5	2·4	2·6	2·5	n.s.
0–9 in.	4·1	3·8	3·9	3·8	0·1
Percentage of water-stable aggregates					
0–3 in.	82	80	81	80	n.s.
3–6 in.	77	79	75	75	n.s.
6–9 in.	69	64	68	67	n.s.
0–9 in.	76	74	75	74	n.s.

L.S.D. = Least significant difference when P = 0·05
n.s. = not significant.

Experimental measurements

The method used for determining the weight of roots has been described elsewhere (4, 6). From March 1952 to March 1953 one soil sample per month was taken from every plot for the determination of root weight, the two replicates being sampled alternately at 14-day intervals. From March 1953 to March 1954 each plot was sampled every 14 days. During the two years each plot was sampled 37 times. The sampling was repeated frequently to eliminate as far as possible errors due to differential seasonal variations in root weight caused by the treatments.

The organic matter in the soil was estimated by determining the percentage of organic carbon by the Walkley-Black wet combustion method; the physical structure was measured by determining the water-stability of the soil aggregates. Details of both methods have been published elsewhere (6). Soil samples for these determinations were taken at the time of sowing, and each subsequent spring and autumn, up to and including the autumn of 1954.

The results in this paper are based on the means of every determination of each measurement.

RESULTS

The botanical composition of the sward had a significant effect upon root weight and percentage of organic carbon, but not upon the percentage of water-stable aggregates (Table 1). The perennial ryegrass (*L. perenne*) swards had a significantly greater quantity of roots than those of either bent (*A. tenuis*) or cocksfoot (*D. glomerata*). The red fescue (*F. rubra*) produced an intermediate weight, nearer to that of the *Agrostis* or *Dactylis* than to that of the *Lolium*, which was not significantly different from either. The heaviest weight of roots occurred in the 0–3 in. layer and it was here that the widest difference was found between the species.

The swards varied a little between the soil layers in the proportional distribution of the root weight (Table 2). For example, in the red fescue swards the percentage root weight in the 0–3 in. layer was slightly higher than in the other species.

The ryegrass swards showed a higher percentage of organic carbon than the other three species in the 0–3 in. and 3–6 in. layers (Table 1); the other differences were not significant. There was also a slightly higher

TABLE 2. Percentage of root weight in each soil layer for individual species and under various managements

	Lolium perenne	*Festuca rubra*	*Agrostis tenuis*	*Dactylis glomerata*
0–3 in.	61	64	61	61
3–6 in.	31	28	30	30
6–9 in.	8	8	9	9

	Grazed hard in autumn	Grazed moderately	Grazed hard in spring	Cut for hay
0–3 in.	62	63	63	60
3–6 in.	30	29	29	31
6–9 in.	8	8	8	9

percentage of water-stable aggregates under the ryegrass (Table 1) but none of the differences in this measurement, due to the botanical composition of the sward, was significant.

Red fescue produced the densest sward, as measured by the number of tillers per unit area (Table 3), which is not surprising considering the smallness of the individual tillers of this species. The fewest tillers were in the cocksfoot sward, which consisted of an almost equal number of large tillers of the sown species and small tillers of volunteer grasses.

The differences in root weight due to management were non-significant (Table 4). Root weights in the swards cut for hay were lower than those in grazed swards. Of the latter, those which were grazed hard in autumn had the heaviest weight, and those grazed hard in spring the lightest. The distribution of the roots between the soil layers was little influenced by these treatments (Table 2), except that the roots were less concentrated in the upper 3 in. of the soil of the hay plots.

TABLE 3. Number of tillers per sq. ft. for individual species and under various managements

	Lolium perenne	*Festuca rubra*	*Agrostis tenuis*	*Dactylis glomerata*	L.S.D.
Sown grasses	465	504	427	202	13
Unsown grasses	61	143	144	201	55
Total of all species	526	647	571	403	31

	Grazed hard in autumn	Grazed moderately	Grazed hard in spring	Cut for hay	L.S.D.
Sown grasses	426	398	397	377	n.s.
Unsown grasses	170	141	158	80	55
Total of all species	596	539	555	457	31

TABLE 4. Effect of management on root weight, percentage of organic carbon and percentage of water-stable aggregates

	Grazed hard in autumn	Grazed moderately	Grazed hard in spring	Cut for hay	L.S.D.
Weight of roots (lb./acre)					
0–3 in.	10,300	10,100	9,800	9,200	n.s.
3–6 in.	5,000	4,700	4,500	4,700	n.s.
6–9 in.	1,400	1,300	1,300	1,400	n.s.
0–9 in.	16,700	16,100	15,600	15,300	n.s.
Percentage of organic carbon					
0–3 in.	5·2	4·9	4·9	4·9	0·3
3–6 in.	4·5	4·3	4·1	4·3	n.s.
6–9 in.	2·6	2·5	2·4	2·5	n.s.
0–9 in.	4·1	3·9	3·8	3·9	0·1
Percentage of water-stable aggregates					
0–3 in.	82	79	82	80	n.s.
3–6 in.	79	75	75	77	n.s.
6–9 in.	70	67	65	66	n.s.
0–9 in.	77	74	74	74	n.s.

The only effect the managements had upon the content of organic carbon in the soil was to increase it in the upper two layers of the plots grazed hard in the autumn (Table 4); these plots also contained a slightly higher proportion of water-stable aggregates in all soil layers, especially in the lower levels. These differences were not significant.

The swards cut for hay were more open and had fewer tillers per unit area than those grazed, largely because of a reduction in the number of unsown grasses (Table 3).

DISCUSSION

One of the most striking features of the results of this experiment is that the botanical composition of the swards had considerably more influence on root weight and organic matter in the soil than had the method of utilizing the herbage. Neither botanical composition nor management had much influence on the physical structure of the soil. The practical implication of this observation is that no matter how the herbage is utilized (within the limits of normal managerial practices) the grass component of a ley will improve soil fertility equally well. If a farmer is able to manage a ley primarily for its ability to improve soil fertility, then the management should be aimed at keeping the legume in the sward and the maintenance of a suitable balance between the leguminous and gramineous components.

If a ley is being sown especially for its fertility-building ability, then the results of this experiment suggest that perennial ryegrass be used as the principal grass in the sward. The differences between the species, however, were small, so that the practical importance would seem doubtful.

The finding that the ryegrass swards produced a higher weight of roots than those of cocksfoot agrees with the results of other experiments (1, 6). The weight of roots under a sward at any one time is the result of the balance between the growth of new roots and the decay of old. A high root-weight may, therefore, be the result of increased growth, of decreased decay or of a combination of the two. The proportion of organic matter in the soil is likewise the result of a balance between the decay of vegetable and animal remains (of which the grass roots provide a high proportion) and the mineralization of organic matter already in the soil. The high root weight of perennial ryegrass was associated with a high proportion of organic matter in the soil, which suggests that this species produced a large quantity of roots, which decayed to produce organic matter fairly quickly.

The high root weight and high percentage of organic matter under the ryegrass swards was associated with a slightly higher percentage of water-stable aggregates, although the differences between the species were not significant. This higher percentage of water-stable aggregates under the ryegrass swards than under cocksfoot is in agreement with the results of Clement and Williams (2).

The lack of a significant difference between the root weights due to the different managements is somewhat surprising in view of the large number of investigators who have reported that the more frequently a sward was defoliated the lower was the root weight (5). It was to be expected, therefore, that swards cut twice per year for hay and aftermath would have a higher root weight than those grazed, which were defoliated several times a year. The hay and aftermath treatment resulted in a very open sward with few plants per unit area, thus counteracting any tendency for a high root weight from very large individual plants.

In the grazing treatments a considerable portion of the herbage would be returned to the soil in the form of dung and urine, but no such return took place on the hay and aftermath plots. The grazed plots would therefore be better manured, and this would be expected to result in greater plant growth with consequently higher root weights. This better manuring of the grazed plots would combine with the low plant density of the hay and aftermath plots to counterbalance any effect of the differences in defoliation *per se*.

Hard grazing in the autumn increased the proportion of organic matter in the soil; apart from this, the method of utilization of the herbage had little effect upon this measurement. This treatment also increased the number of tillers per unit area and the proportion of water-stable aggregates in the soil, although in the latter instance the differences were non-significant. The somewhat anomalous behaviour of this treatment warrants further investigation.

The managements used in this experiment were not so extreme as to be outside the realm of reasonable agricultural practice, nor were they continued long enough to produce major changes in the botanical composition of the sward or in the soil. If more extreme managements had been applied, or those used in this experiment had been continued longer, larger differences would no doubt have been observed. More extreme managements would, however, have taken the experiment outside the range of agricultural practice, while a longer period of application would have invalidated the comparison of the species.

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FARMERS' REASONS FOR NOT ADOPTING CONTROVERSIAL TECHNIQUES IN GRASSLAND FARMING

D. SHEPPARD

*The Social Survey, Central Office of Information**

It is commonly said that 'resistance to change' is a basic factor preventing farmers from adopting new techniques, but such a statement depends on an external judgement as to the suitability of the technique studied for the farmer. In a recent survey, farmers were asked to give their reasons for not taking up recommended techniques for grassland farming, and these reasons are examined. In some cases it is clear that the farmer has no good reason for not using the technique except that he dislikes it, and differences between techniques in this respect are discussed.

INTRODUCTION

As Dadd and Osborne remarked (2), when a farmer does not adopt a technique which is commonly used, and generally recommended, this is often attributed to a 'resistance to change' (5). The use of such a phrase implies that such behaviour must be illogical, because it appears to be so from the standpoint of the technical expert. The farmer's own view on the suitability of the technique may not even be obtained, let alone given full consideration.

As an example of such an approach, there is a much-quoted paper by Ryan and Gross (9) in which various conclusions are drawn about the time taken to adopt a new cereal variety. This is a change which involved no vast reorganization of farming policy and it appears that the new variety had considerable, and obvious, advantages over other varieties. Two findings are quoted as of interest: first, the number of farmers adopting the technique increased only slowly; second, although all who adopted the technique used the new corn variety on only a part of their corn acreage during the first year in which they used it, the proportion of the acreage was greater among later adopters. However, in a later paper, Ryan (8) pointed out that there was not much hybrid seed available in the early years, though he claimed, without saying how he could know this, that there would have been sufficient for anyone who wished to purchase it. If farmers with larger farms were the first to try the new variety†, it may be that these had their total corn acreage split up into a larger number of units, and if all farmers who tried out the new variety tried it out on one field only at first, this would bring about such an apparent change in the extent to which farmers committed themselves to the new variety in the first years. Thus, one might explain away an apparent unwillingness to adopt a new technique in terms of factors such as availability or the size of the unit. But because the investigators had not questioned the farmers on this topic, one can only speculate as to which type of explanation is more likely to be correct.

An investigation on this topic may be more worthwhile if innovations are selected which vary according to the degree of change in farming policy involved and also in the degree to which they have been accepted. Thus it is no great hardship to make a change in a seed variety, but a decision to abandon beef rearing in favour of dairy farming involves a much more drastic change. Again, it is a different matter to cut and cart kale, when everyone else in your district does this, from doing so when 90% of the farmers in the district self-feed their kale with the aid of an electric fence. With the rarer techniques, there is the additional complication that some farmers may not even have heard of them, so that it would not be fair to judge such farmers as having chosen not to use them.

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*The writer wishes to point out that the views expressed in this paper are his own and do not represent the official views of a government department.

†There is much evidence that farmers with larger farms are usually the first to adopt new techniques, although this does not apply to one instance of adopting a new cereal variety in this country (14).

In the course of an enquiry carried out for the Ministry of Agriculture, Fisheries and Food in 1957 (11) farmers were asked to give their reasons for not using certain techniques, and it may be of interest to consider these, bearing in mind the criteria just discussed.

THE SURVEY

Data were obtained from 446 grassland farmers in 10 districts in England and Wales, with a maximum of 50 farmers in each district. A grassland farm was defined as one where the total acreage was 20 acres or more, of which at least 5 acres were grass other than rough grazing. Because, in some districts, the 50 farmers interviewed represented a small proportion of the available farmers, data obtained from such districts were given an increased weighting. This gave a new weighted total of 652 farmers. The districts were selected at random from a complete list of groups of parishes in England and Wales, and the farmers to be interviewed were selected at random from lists of farmers in each district. Weighting, too, was done on a basis of random

TABLE 1. The use of techniques on grassland farms

Techniques applicable to all farmers (652 farmers)	Number of farmers	Percentage of all farmers
Sheep		
Keeps sheep	232	36
Does not keep sheep	420	64
*Fertilizers**		
Uses straights, compounds and other types of fertilizers	391	60
Uses lime or basic slag, but no other type of fertilizer	112	17
Uses none	148	23
Electric fence		
Uses electric fence and has done so since 1951 (or before)	133	20
Uses electric fence and has done so only since 1952 (or later)	152	23
Has not used electric fence†	365	56
Silage		
Makes silage and has done so since 1954 (or before)	55	8
Makes silage and has done so only since 1955 (or later)	60	9
Did make silage, but does not now	114	17
Has never made silage	421	65
Tripods for haymaking		
Uses them now	8	1
Does not use them now, but has done	35	5
Never used them, but says would if had labour staff	109	17
Never used them, and does not know if would if had labour staff	26	4
Never used them and would not if had labour staff	474	73
Technique applicable to dairy farmers only (332 farmers)		
Milk recording		
Records using N.M.R. method	104	31
Records using P.M.R. method	18	5
Records privately	26	8
Does not record milk	184	56

Note: One farmer gave a fertilizer type which could not be identified, two gave no date for their first use of electric fence and two no date for their first use of silage. The corresponding totals are therefore reduced.

*For this purpose 'straights' include nitrogenous fertilizers but exclude basic slag. The latter is considered separately because its use is more 'traditional'.

†This category may include some farmers who once used an electric fence, but were not using it during the year of the survey. No direct question was asked on this point.

selection, so that the data should be representative of grassland farmers as a whole, apart from sampling errors due to the small size of the sample. Interviews were obtained with 95% of the farmers originally selected.

THE TECHNIQUES

Reports of rural sociology studies tend to give the impression that there is no difficulty in finding universally applicable farming techniques. In practice, this is not so easy. In this case, four techniques were selected which appear from the mass-approach sources (e.g. at agricultural shows) to be universally recommended, though this is not to say that a good adviser would recommend them to everyone.[4] To make a somewhat sweeping generalization, it could be said that all these grassland farmers could profitably apply fertilizer to their grassland during the autumn or spring; could use an electric fence to control grazing; could make silage and could use tripods for haymaking. Further, for those who are dairy farmers, it could be said they could profitably use milk records and, with less certainty, that all grassland farmers could profitably use sheep on their farms. The extent to which each of these farming activities is practised is shown in Table 1. Excluding sheep from consideration, some further details are also given which indicate 'progressiveness', using the term 'progressiveness' to indicate a willingness to try new, as distinct from traditional, farming methods. Table 2 shows which techniques tend to be used together, of those which can more aptly be said to be suitable for all farmers. It can be seen that all associations are positive, indicating that a farmer who uses one technique is likely also to use the others, and also that there is no rivalry between techniques such as might have been expected if, say, those who make silage never make hay if they can help it. In the matrix for dairy farmers the associations are generally less marked, but this is a statistical effect which is to be expected with a more homogeneous group.

It would not be easy to say which of the four generally applicable techniques involves the

TABLE 2. The relationship between grassland techniques

All grassland farmers (652 farmers)

	Users of electric fence	Users of silage	Users of tripods
Users of 'artificials'	+0·186***	+0·245***	+0·107*
Users of electric fence		+0·384***	+0·107*
Users of silage			+0·250***

Dairy farmers (332 farmers)

	Users of electric fence	Users of silage	Users of tripods	Users of milk records
Users of 'artificials'	+0·171**	+0·212***	+A	+0·186**
Users of electric fence		+0·328***	+0·064	+0·239***
Users of silage			+0·231***	+0·275***
Users of tripods				+0·129*

Notes: 1. The values shown are those obtained by the formula $\sqrt{\chi^2/n}$. A value of +1·0 would mean that there is a perfect association between two techniques, so that all farmers using one also use the other; a value of −1·0 would mean that there is a perfect negative association in that all farmers using one technique do not use the other.

2. Stars placed by each value indicate the significance of χ^2 for each association. Where there are no stars, the association is not statistically significant; one star indicates $P<0{\cdot}05$; two stars indicate $P<0{\cdot}01$ and three stars $P<0{\cdot}001$.

3. The letter A is used in place of a value for $\sqrt{\chi^2/n}$ in one case where the numbers in the χ^2 cells were too small to make it permissible to compute the value. The degree of association was quite high in this case, even though no exact numerical value could be given.

greatest change in the farm routine or policy. None involves any major change, though it is true that special equipment or materials would be essential for everything except silage. There can be no doubt, however, that the introduction of sheep onto a farm where these have not been kept before would be by far the greatest change of all those considered. It will be convenient to consider first the reasons for not introducing sheep, and then the reasons for not using tripods, silage, electric fences and fertilizers.

Sheep

422 farmers did not keep sheep, and these were asked if they would do so if they could grow more and better grass. Only 29% of these said that they would and those who would not were asked why not. Their replies are shown in Table 3.

It can be seen that some of the reasons, such as 'sheep are a nuisance', probably reflect an attitude of mind rather than any valid criticism, but there are many quite reasonable objections. Thus the presence of many dogs, or the difficulty of getting experienced labour would, if true, be sound reasons. Some of the reasons refer to circumstances which could be remedied without too much trouble, the objection which refers to fencing being one example. Again, in each of the districts studied, there are farmers who keep sheep and probably these have had to cope with equally unfavourable conditions.

Tripod-hay

Even if those who have used tripods in previous years, but not during the year of the survey, are included with those using them for haymaking in the year of the survey, the total number is still small (7%; standard error 2%). All who have never used them were asked why they had not done so and the replies are shown in Table 4. It can be seen that the principal objection refers to the work involved, and to tripods being only appropriate in wet seasons or in districts with a high rainfall. The apparent inconsistency that some say their acreage is too great, while others say theirs is too small, to use tripods, appears more reasonable on a further analysis: among the former group, most have over 150 acres of grass, while most of the latter have 50 acres, or less. 7% had no reason to offer, while somewhat less than 2% had the perfect reason, that they do not make hay. The reasons that are given are mostly technical, though, again, other farmers who do make tripod-hay must have overcome or chosen to ignore the same objections.

An earlier survey (10) had shown that farmers tended to blame the time factor, or a labour shortage, for not using tripods, so farmers in this survey were asked if they would use tripods if they had the staff available. Many said that they would not, even then. In view of comments made in the earlier survey about the cost of tripod-hay, farmers in this survey were asked to say how much it would cost to make.

TABLE 3. Reasons farmers give for not wishing to take up sheep farming

Reasons	Number of farmers	Number of farmers giving reasons, as a percentage of all farmers who would not keep sheep
The farm is not suitable for sheep (e.g. too scattered, too small, wrongly situated)	50	18
It is difficult to get experienced labour	44	15
I have had no experience with them myself	43	15
Sheep are a nuisance, or are troublesome; I don't like them	43	15
I specialize in other things (e.g. cattle, crops, pigs)	40	14
The land is unsuitable for sheep (e.g. wet, marshy)	34	12
The fencing, or hedging, is not good enough	31	11
There are too many dogs around here	27	10
The expense would be too great (e.g. in labour, or repairing fences)	14	5
Other replies	6	2
Total of replies	332	
Total of farmers	284	

TABLE 4. Reasons for not using tripods given by those who have never used them

Reasons	Number of farmers	Number of farmers giving reasons, as a percentage of all farmers who have never used tripods
Too much labour, or work, or trouble involved	193	32
Better results with other methods	134	22
Don't find it necessary in this district	99	16
Doesn't pay, or not economical, or expensive	87	14
A dry climate here, only useful in wet weather	36	6
Used cocks instead	22	4
Farm is too small; too little grassland	21	3
Don't make hay, or much hay	10	2
Make too much hay to use tripods	7	1
Other replies	24	4
Don't know. No answer	43	7
Total of replies	676	
Total of farmers	609	

Of those who had never made it, 63% would not attempt any estimate and a further 16% would only say that it would cost more than the method of haymaking they used. The average figure given by those who did give an estimate was £6.2.0 a ton. For 1957, this average was probably an over-estimate of the cost, even supposing rent, farm overheads and a share of the establishment charges were all taken into account (6, 15).

With a technique which is as rarely used as this in Britain, there is a danger that some farmers may not even have heard of it. No evidence was obtained on this aspect in this enquiry, though a few farmers seen in the 1956 enquiry had had to have the technique explained to them (10). The present survey showed that 24% of the farmers interviewed knew of another farmer who had made hay on tripods, while half of those also knew what quality of hay was made.

Silage

18% of farmers made silage in the year of the survey (standard error 3·6%) and a similar number had made it in previous years but were

TABLE 5. Reasons for not making silage given by those who have never made it

Reasons	Number of farmers	Number of farmers giving reasons, as a percentage of all farmers who have never made silage
Insufficient stock; wrong type of stock; no dairy cattle	104	25
Small farm; insufficient acreage; small or hilly fields	62	15
Too much work or time needed; haven't the time, or the labour	57	14
Use plenty of hay, roots, swedes, turnips, surplus crops	47	11
Have not got the equipment or the facilities	40	10
Prefer hay; prefer roots or swedes	39	9
Never thought about it; not interested; get on all right without it; don't know anything about it	29	7
Don't like it; don't believe in it	20	5
Expensive; wasteful; it might not pay; the equipment is expensive	15	4
Don't like the smell	9	2
Other replies	16	4
Total of replies	438	
Total of farmers	421	

not doing so in the year of the survey. Those who had never made it were asked why not and the replies are shown in Table 5.

Few of these reasons are technical, and some are scarcely even rational. It is easy to believe that there is some sort of resistance to making silage which goes deeper than mere technical objections. The smell of silage is one factor of importance, for 29% of those who had never made it said that they objected to the smell when asked about this, as compared with 13% saying this among those who make silage. As one farmer succinctly put it—he had to make a choice between making silage and keeping his foreman, so he kept his foreman. Again, silage is seen by some as a rival to hay—the traditional method of conserving grass—rather than as a complementary method of storage. In view of this, each farmer was asked if he thought that silage could be as good as good hay: of those making silage in the year of the survey, 73% said silage could be as good, as compared with 59% of those who had once made silage, and 27% of those who had never made it. The reasons given as to why silage could not be as good are shown in Table 6, and it can be seen that few could be described as technical, let alone technically sound. The statements that 'Hay is a *natural* food' and that 'Silage wears the cows out' are particularly interesting. However, it is not altogether hard to understand how the appearance and smell of silage, as compared with sweet hay, could seem important to an unsophisticated farmer.

Electric fences

44% of farmers were using the electric fence for controlling the grazing of grass in the year of the survey (standard error 4·7%). It was assumed that those who were not using it had never done so previously and these farmers were asked why they did not control grazing. The replies are shown in Table 7. Apart from those who admit they do not know, the reasons given are usually technical, though it would not appear that many of them are very sound. No data are available to show if those who do not use an electric fence have smaller fields, or less stock, than those who do use one, but it may well be that there is no such difference. Obviously, 'no stock' is a valid objection and many experts would agree that using an electric fence with beef cattle is unlikely to bring about an increase in profits. However, cases have been quoted of farmers using an electric fence profitably when rearing beef animals (1, 4).

Artificial fertilizer

77% of these farmers had applied artificial fertilizer to their grassland in the previous autumn or spring (standard error 3·7%). Those who had not done so were asked why not and the replies are shown in Table 8. As with tripod-hay, the reasons given are mostly

TABLE 6. Reasons given by farmers for silage not being as good as good hay

Reasons	Number of farmers	Number of farmers giving reasons, as a percentage of all farmers saying silage not as good
Vague remarks such as: hay is best, prefer hay, good feed, best for cattle	98	48
Don't know in what way; just prejudice; no experience of silage	22	11
The trouble involved in carting or in making silage	17	8
Hay holds its vitamins, or proteins, better	11	5
Hay produces more milk	11	5
Silage not suitable in *winter* for sheep, or for cattle	10	5
Gives cattle indigestion; they scour or go thin; silage wears them out	9	4
Hay is a natural food	6	3
Silage affects the taste of milk	4	2
Other reasons	20	10
Total of replies	208	
Total of farmers	205	

TABLE 7. Reasons given for not using controlled grazing

Reasons	Number of farmers	Number of farmers giving reasons, as a percentage of all farmers not controlling grazing
Has small fields	106	30
Has insufficient or no stock	49	14
We change stock from field to field	38	11
Takes too much time	33	9
Not necessary for type of stock (beef, pigs)	30	8
Drinking water supply difficulties	26	7
Land awkwardly placed or unsuitable	18	5
Farm not large enough; not enough pasture	12	3
Too much stock	7	2
Has natural barriers, or ditches, etc.	4	1
Don't know; no answer; never thought; never have controlled grazing	47	13
Other replies	26	7
Total of replies	396	
Total of farmers	360	

Note: An additional fourteen farmers described themselves as using controlled grazing, though in fact they had no electric fence. Eight of these had small fields.

TABLE 8. Reasons given for not applying artificial fertilizers to grassland

Reasons	Number of farmers	Number of farmers giving reasons, as a percentage of all farmers not applying artificial fertilizer
Not necessary, or the land is rich enough now	46	30
Have sufficient farmyard manure available	29	19
Gave it plenty last spring	20	14
Too expensive; can't afford it	11	7
Not on farm in period in question	10	7
Artificials are inferior to farmyard manure; they starve the ground; they do not give good results	7	5
Labour shortage; I have not had time	2	2
Other replies	23	16
Total of replies	148	100
Total of farmers	148	

technical. The reason that 'the land is rich enough now' may be based on some scientific evidence, for 65% of the farmers who did not apply artificials in the year in question had had at least one soil analysis done on their farm, including analysis for lime, under this heading. The idea that artificials starve the ground is quite a popular one among these farmers and it may be relevant here to give the replies to a contentious question: 'Which do you really think is best for grass—farmyard manure or artificial?' 37% of all farmers voted for artificials and 40% for farmyard manure; 20% said both were needed and 3% did not know. The use of farmyard manure is, of course, traditional, but this is not the whole explanation. It is clear, from some of the reasons given for preferring it, that it also gains because it is thought of as 'natural'. However, the idea that something which is natural must be best is held by other people as well as farmers (12, 13).

CONCLUSIONS

In discussing some of the results produced by the survey among grassland farmers, it has been shown how farmers justify the fact that they have not adopted certain grassland farming techniques and methods. An attempt has been made to evaluate these reasons and to see how many appear to be reasonable on technical grounds and how many seem only to reflect a conservative outlook, or 'resistance to change'.

It will be appreciated that there may of course be 'resistance to change' even where the farmer can give apparently sound technical reasons for not using a technique. Psychologists use the term 'rationalization' when a person, without necessarily realizing he is doing so, devises reasons which sound good to justify an opinion based on other motives. No doubt some of the farmers interviewed were rationalizing, but the extent to which this occurred can only be surmised.

A second factor to bear in mind is the extent to which a farmer has made a deliberate choice between alternative courses of action. To take an example, a farmer who learnt dairy farming from his father and carried on with this when farming on his own, may never have deliberately thought out the advantages and disadvantages of including sheep among his livestock. If such a person is suddenly faced with a question as to why he would not introduce sheep, it would be too much to expect that he should produce carefully thought-out and reasonable answers.

While it might be unwise to make too much of differences between techniques according to the proportion of non-technical reasons given for not using them, it is still noteworthy that such reasons do occur quite commonly. When the independent opinion of a technical expert is that a farmer could use a technique profitably, and the technique is sufficiently widely used for it to be certain that the farmer concerned knows about it, but yet he is unable to produce any sound reason for not using it, then it may well be fair to assert that the important factor is a resistance to change. If this is agreed, then it seems clear from this investigation that this trait is quite common among farmers.

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THE PRODUCTIVITY OF LAND AND FEED USED FOR LIVESTOCK PRODUCTION IN BRITAIN COMPARED WITH BELGIUM, DENMARK AND THE NETHERLANDS

PART I

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Comparative productivity measures are now commonly used in farm-management studies for assessing the efficiency of resource use on farms. In any attempt to use similar techniques for comparing the agricultures of different countries, there are obviously greater problems. Differences in soil fertility and climate cannot be satisfactorily allowed for in inter-country comparisons, whereas in inter-farm studies a fairly homogeneous sample can be selected. Farms within the same country operate under broadly similar conditions of prices for resources and for products, whereas between countries the conditions may be very different; and this may influence both the level of output and its composition, and hence the productivity of any one resource.

Nevertheless, some attempt at inter-country comparison seems worth while, particularly when British agriculture is said to be non-competitive at prices ruling in world markets. The purpose of this study is to compare the feed economy of British livestock production with that of Belgium, Denmark and the Netherlands. Livestock products constitute approximately two-thirds of the output of British farms; and feed is easily the most important cost in livestock production.

In this paper we are concerned with estimating the ratio between the physical quantities of land and feed and the physical volume of livestock output. It must be remembered, however, that such a ratio does not measure the overall economic efficiency of livestock production, for it does not take into account the money cost of the land and feed, the inputs of labour and capital or the actual prices received for the livestock produced. Nevertheless, an enquiry into the productivity of land and feed in physical terms is an essential part of any investigation into economic efficiency of agriculture.

The study applies to 1953 and 1954—the last two years for which complete statistics were available when this investigation was started. Belgium, Denmark and the Netherlands were selected for this comparison because their climate is fairly similar to that of Britain.

METHOD

If a ratio of feed to output is to be calculated, a common denominator must be found for all classes of feed, and another for all types of livestock products. As regards feed, it was decided to express this in terms of the land *area* devoted to livestock. This measure of feed input is less subject to error than any attempt at estimating the *quantity* of feed, e.g. in terms of starch equivalent. This is because the *nutrient content* of *grazing* can only be estimated indirectly, by assuming certain theoretical requirements for livestock feeding; whereas the area of grassland is known.(1) The difficulty of converting imported feedingstuffs and by-products of non-feed crops into an equivalent land area was solved by expressing these classes of feed in terms of the land area which would be required, at each country's average yield of grain per acre, to produce the same quantity of starch equivalent. Details of the methods by which "acre-equivalents" of all feeds were estimated are given in Appendix 1.

For the *output*, the money value at constant prices seems to be the obvious common denominator. Since, however, the relative prices of different products vary from country to country, two separate calculations were

TABLE 1. Estimated acre-equivalents of feed per £1000 of livestock production (Average of the years 1953 and 1954)

	Belgium	Denmark	Netherlands	U.K.
1. *With production valued at 1953 British prices*		Acre-equivalents		
(a) Home-grown feed:				
Grass	7·70	6·33	8·78	20·71
Other bulky foods	1·68	2·87	0·95	1·81
Concentrates (incl. grain)	4·33	6·12	3·02	6·11
Sub-total	13·71	15·32	12·75	28·63
(b) Imported feed:	4·70	1·70	4·10	6·04
TOTAL FEED	18·41	17·02	16·85	34·67
2. *With production valued at 1953 Danish prices.* (In £ at current rate of exchange)				
(a) Home-grown feed:				
Grass	11·09	9·34	13·13	28·03
Other bulky foods	2·43	4·23	1·43	2·45
Concentrates (incl. grain)	6·23	9·02	4·51	8·26
Sub-total	19·75	22·59	19·07	38·74
(b) Imported feed	6·77	2·50	6·14	8·17
TOTAL FEED	26·52	25·09	25·21	46·91

made, one at 1953 British prices, and the other at 1953 Danish prices (Appendix 2).

Area/output ratio

A division of the two-year total of acre equivalents of each class of feed by the two-year total livestock output gives a ratio which we shall call area/output ratio. The results of these calculations are given in Table 1. They show the number of acre-equivalents required to produce a given output of livestock products. Since this and subsequent tables are based largely on estimates, the degree of accuracy suggested by the figures is somewhat spurious. However, keeping the decimals is convenient for some of the calculations mentioned later in the paper.

The striking conclusion which emerges from these figures is that Britain uses approximately twice as many acre-equivalents per £1000 of livestock production as any of the other three countries. The table also shows that a change in the price system adopted for valuing the output, influences each country's area/output ratio, both in the absolute and relative sense, i.e. it alters both the numerical value of the ratio and the position of each country's ratio in relation to the other countries. It can be seen that all the countries have lower area/output ratios at British than at Danish prices. British farmers obtain a higher gross return per acre-equivalent of feed than they would do if our prices were the same as those prevailing in Denmark, but it is the high relative prices which make our products non-competitive.

The second effect of changing the price basis is seen, for example, in the fact that, at British prices, the Netherlands have the lowest area/output ratio, but at Danish prices, Denmark's ratio is the lowest. This is because—in relation to the price of meat—the British milk and egg prices are higher than the Danish, and both milk and eggs form a higher proportion of the Netherlands' than of Denmark's output.(2)

With each livestock product valued at the same price for all the countries which are being compared, the area/output ratio will depend, amongst other things, on the yield of each crop grown and used for livestock feeding and upon the conversion rates of crops fed. Thus, a low area/output ratio may be due as much to high crop-yield as to high efficiency of converting these crops into animal products. Both crop yields and conversion rates vary not only between countries, but also between the different kinds of feed and livestock within each country; the area/output ratio will, therefore, be affected by the proportion of different crops grown and of different livestock kept. Some of these factors are examined in the following pages; henceforth all the calculations are made with output valued at 1953 British prices, unless stated otherwise.

Area/output ratio in different branches of livestock production

On the basis of the different countries "commodity cost" data (1–8) and of the total number of acre-equivalents used in each country, it has been possible to make an approximate estimate of the acre-equivalents required per £1000 of production for each of the broad classes of livestock; in addition, the U.K. data have made possible separate estimates for milk-, beef- and sheep-production. All these estimates are given in Table 2. Since the commodity cost data are partly based on subjective estimates and on relatively

TABLE 2. Estimates of acre-equivalents per £1000 of production (at 1953 British prices) in different enterprises (Average of the years 1953 and 1954)

Type of livestock or product	Class of feed	Belgium	Denmark	Netherlands	U.K.
		Acre-equivalents			
Pigs	Grass and other bulky foods	—*	2	—*	—*
	Concentrates†	15	11	14	19
	TOTAL	15	13	14	19
Poultry	TOTAL	15	12	14	20
Grazing livestock (cattle, sheep, horses, etc.)	Grass and other bulky foods	16	17	15	37
	Concentrates†	5	4	3	7
	TOTAL	21	21	18	44
Milk	Grass and other bulky foods				26
	Concentrates†				9
	TOTAL				35
Beef	Grass and other bulky foods				57
	Concentrates†				4
	TOTAL				61
Sheep	Grass and other bulky foods				43
	Concentrates†				4
	TOTAL				47

*Less than 0·5 acre equivalent.

†"Concentrates" includes grain.

N.B. These figures do not include milk or milk products fed to livestock. It is possible, however, to estimate that those feeds, expressed as acre-equivalents of coarse grain, were fed to *pigs* at the following rates per £1000 of production: Denmark 2·1; Netherlands 0·79. (No comparable information is available for Belgium or Britain).

small sample surveys, the approximate nature of these figures must be emphasized.

The table confirms the well-known fact that, at prices ruling in 1953 and, indeed, over a long period, pigs and poultry use less land in relation to the value of their output than do grazing animals. Britain's ratio of area to output appears to be higher than that of any of the other three countries in all the three broad classes of production, and the difference between the British ratios for the grazing and non-grazing livestock is exceptionally large.

Composition of output

In view of the different area/output ratios in the several branches of production, one would expect the percentage composition of livestock output to affect the overall area/output ratio in each country. The four countries studied do differ in the composition of their respective "baskets" of livestock products, as shown in Table 3.

TABLE 3. Percentage composition of livestock production in the 2-year period 1953-54. (At 1953 British prices)

Products	Belgium	Denmark	Netherlands	U.K.
	%	%	%	%
Pigmeat	23·7	37·2	19·6	20·6
Eggs	14·6	10·1	14·6	16·0
Poultry	1·8	1·6	1·5	2·9
Milk	43·4	39·1	51·1	36·0
Beef and veal	15·1	10·9	11·9	16·8
Mutton, lamb and wool	0·3	0·1	0·7	7·4
Horse and other meat	1·1	1·0	0·6	0·3
All products	100·0	100·0	100·0	100·0

However, even at the British area/output ratios, which show a particularly great divergence between the productivity of feed area used for grazing and non-grazing enterprises (see Table 2), these differences in the composition of output account only for the following percentages of the total difference between Britain's and the other countries' area/output ratios:(3)

Belgium	1·5%
Denmark	16·5%
Netherlands	5·9%

If our "basket" of livestock products had been identical with Denmark's, then, without any change in crop yields or feed conversion rates, Britain would have required only 31·76 acre-equivalents per £1000 of output, instead of the 34·67 actually used, compared with Denmark's 17·02 acres. To achieve a reduction in the area/output ratio in this way would, however, entail increasing considerably the share of pigmeat in the total British production, increasing the share of milk slightly, and reducing the share of eggs, poultry, beef and sheep products. In many respects, this would mean increasing the output of products which are now least competitive with imports, and would require a substantial rise in imports of concentrates which the Government has been concerned to avoid over the last few years.

Are there any more practical ways of reducing Britain's area/output ratio through a change in the "basket of goods"? It would appear from the figures given in Table 2 that some reduction might be expected if milk output were increased at the expense of beef production;(4) such a change would seem possible, at least with regard to the land involved, for some of the beef is produced in districts suitable for dairy farming. However, any additional milk produced would almost certainly have to be sold for manufacture, and—because of the low prices obtainable—the area/output ratio in this additional production would be higher than that in beef production. Therefore, if we assume that changing the quantity of beef would not affect its price and that the market for liquid milk cannot be expanded, a transfer of resources from beef to milk production can only lead to an increase in Britain's overall area/output ratio.

Inter-country differences in feed conversion rates

It was pointed out earlier in this article that not only do area/output ratios vary between different branches of production, but for the same product each country has a different ratio. This is due partly to the differences in the yield of feed per acre in the countries concerned. But for *pigs and poultry*, which are fed mainly or exclusively on concentrates, these

TABLE 4. Average yields of certain crops

Crop	Belgium		Denmark		Netherlands		U.K.	
	1952	1953	1952	1953	1952	1953	1952	1953
				Tons per acre				
Potatoes	9·7	8·6	8·4	7·0	10·8	9·9	7·9	8·4
				Cwt. per acre				
Wheat	27·1	26·3	32·7	31·9	31·9	30·3	22·7	24·0
Rye	21·5	20·7	20·7	19·9	21·5	19·9	17·9	19·5
Barley	23·9	24·7	30·3	27·9	27·9	21·5	20·5	22·7
Oats	22·3	23·1	28·7	27·1	25·5	24·7	19·2	19·9

Source: F.A.O. Yearbooks and national statistics.

N.B. Most of the feed consumed during the period under investigation (years 1953 and 1954) was obtained from the 1952 and 1953 harvests.

yield variations can be eliminated so that the remaining differences in the area/output ratio can be attributed to the unequal feed conversion rates. Raising the efficiency of feed conversion in pig- and poultry-farming to Belgian, Danish or Dutch standards, would by itself eliminate approximately 5–6% of the total difference between the overall area/output ratio of Britain and the other countries.⁽⁵⁾

There is no detailed information available to the writer on the actual feed conversion rates prevailing in each of the other branches of production in the four countries. (Milk and meat production are treated as one enterprise in Danish and Dutch cattle enterprise studies.) However, by applying theoretical feed requirements, one concludes that, for example, at Dutch milk yields per cow, about 12% less starch equivalent may be required per gallon of milk than at British yields.⁽⁶⁾

Yields of crops and grass

As already mentioned, the area/output ratio in each branch of livestock production is affected not only by the feed conversion rate, but also by the quantity of feed produced per acre. For inter-country comparisons, the crop yields shown in Table 4 are a good indication of the relative feed yields per acre.

It can be seen that there are appreciable differences between countries, with Britain's yield the lowest in practically every case. In fact, raising grain yields to the other countries' standards would by itself eliminate the following proportion of the total difference in the area/output ratio between the U.K. and these countries: Belgium 9·7%, Denmark 19·5%, Netherlands 12·1%.

No equally reliable information exists with regard to grassland and other bulky feeds (with the exception of potatoes), although one suspects that it is here that the greatest differences lie. By applying the residual (or balance) method, based on theoretical feed requirements of livestock,⁽⁷⁾ an O.E.E.C. survey (11) estimates the 1951–2 utilized yields in thousands of fodder units⁽⁸⁾ per adjusted acre of grassland as follows: Netherlands 1·9, Denmark 1·6, Belgium 1·5, United Kingdom 1·2. This means that an acre of grassland in the Netherlands satisfies the same nutrient requirements as 38 cwt. of barley, in Denmark as 32 cwt., in Belgium as 30 cwt., and in the U.K. as 24 cwt.⁽⁹⁾ If we assume that the same relationship holds good for yields of other bulky foods, we can estimate that raising British yields of grass and other bulky foods to the other countries' standards would by itself eliminate the following percentages of the differences between Britain's and the other countries' overall area/output ratio: Belgium 23%, Denmark 31·7% and the Netherlands 45·5%.

NOTES

(1) Since the U.K. pastures include a large proportion of hill and rough grazings, the U.K. grassland area was adjusted by the method explained in Appendix 1.

(2) In Appendix 3 can be found a more detailed explanation of the influence of the price system on the area/output ratio.

(3) For the purpose of this paper, the differences due to the various causes were calculated on the assumption that the total U.K. level of livestock output might be achieved with a different "basket of goods" and/or at different grass- and crop-yields and feed conversion rates.

(4) Compare also figures quoted by Renne (9) from an American investigation. These indicate that *14 acres* were required to produce 1,400,000 calories in the form of *beef*, whereas the same number of calories in the form of *milk* was obtained from *4 acres*.

(5) This assumes the feeding of milk by-products to pigs in Britain at the same rate per lb. of meat produced as in the other countries. It seems likely, however, that the quantity of milk by-products available in Britain would not be sufficient for feeding them to pigs at the Belgian, Danish or Dutch rates because a much lower proportion of milk is used for manufacture in Britain than in those countries. In so far as grain would have to be fed in place of some of the milk by-products, the reduction in the area/output ratio would be less than given in these estimates: e.g. at Danish pig and poultry feed conversion rates, but with all milk products fed to pigs replaced by grain, only 2·5% of the total difference would be eliminated.

(6) Estimated milk yields per cow, calculated from Ref. 10 (1953–4 average; gal.): Netherlands 820, Denmark 771, Belgium 711, U.K. 627. Food requirements estimated from Ref. 15. Since this is only a rough estimate, a constant marginal return to feed is assumed.

(7) The residual method has serious drawbacks. Thus, the "theoretical" requirements are based on trials which do not cover the full range of farm conditions. Also, the method assumes complete utilization of hand-fed foods, but not necessarily of pasture. (See e.g., Ref. 12, p. 86–7). Some alternative estimates are given in Part 2 of this paper, in the section entitled "Differences in the Composition of Feed Input".

(8) One Fodder Unit = feeding value of one kg. of barley.

(9) The British Grassland Utilization Committee's report (12) gives the effective usage of grass in the U.K. in 1950/1 as 15 cwt. starch equivalent per acre, which is equivalent to 21·4 cwt. of barley. (It is obvious from the context that rough grazings were excluded in arriving at the estimate quoted by the Committee.)

(To be continued)

APPENDIX

1. *Calculation of acre-equivalents*

The area of *permanent and temporary grassland, roots and green crops* was obtained from the F.A.O. Yearbooks (10) and from national statistics (13, 14, 16–18). For the U.K., the area shown in Table A under Permanent Grassland is an *adjusted* figure, calculated in the following manner: Outputs per acre of hills and lowlands were calculated from data published by Davidson and Wibberley (19) and it was assumed that an acre of permanent grassland is equivalent to 4 acres of rough grazings. As a result, the following scale was used:—

1 ac. of permanent grass, lowlands = 1·00 ac.-equivalent
1 ,, ,, ,, ,, hills = 0·22 ,,
1 ,, ,, rough grazings, lowlands = 0·25 ,,
1 ,, ,, ,, ,, hills = 0·055 ,,

The proportion of hills to lowland area given by the above-mentioned authors for Great Britain was assumed to be applicable to the United Kingdom as a whole. The resulting estimates are compared below with the actual figures given in Ref. 14.

(The adjusted area would be greater than shown here if one based the calculation on the output estimates published by Nash (20).)

No adjustments were made in respect of the other three countries, which have no hill pastures within the meaning of Davidson and Wibberley's work, and only an insignificant proportion of land conforming to the British definition of "rough grazing".

The "root equivalent area" of *sugar-beet tops* is based on the ratio of starch equivalent of tops to total starch

	Year 1953	Year 1954
	(1000 acre-equivalents)	
Adjusted area of permanent grassland		
Permanent grass, lowlands	11,965·0	12,204·7
,, ,, hills	217·4	222·4
Rough grazings, lowlands	1191·1	1191·1
,, ,, hills	667·2	667·2
TOTALS	14,040·7	14,285·4
	(1000 acres)	
Actual area		
Permanent grass	12,952·6	13,213·5
Rough grazings	16,890·1	16,880·2
TOTALS	29,842·7	30,093·7

equivalent of the sugar-beet crop, calculated from Ref. 21.

The quantities of *other feeds* were estimated on the basis of F.A.O. (10) and national statistics (21–26). In those cases where the original data applied to split years, it was necessary to allocate appropriate quantities to the calendar years 1953 and 1954, so as to bring them in line with the periods of livestock production. The home-produced straw and chaff were ignored, as the amounts fed could have been obtained from home-grown cereals fed to livestock, and did not therefore require any additional land.

For the purpose of Table A, the quantities of home-grown potatoes, cereals and pulses were converted into *acre-equivalents* on the basis of average yields prevailing in each country (10, 14, 23, 26, 27). The same basis was used for imported cereals and pulses of those species which are also grown in the importing country. For other imported feedingstuffs and for milling offals and industrial by-products of home-grown crops, the number of acre-equivalents is based on the area of home-grown oats and barley which would produce the same quantity of starch equivalent.

The estimated total acre-equivalents of each feed are shown in Table A.

2. *Product prices and total production*

Prices received by British and Danish farmers for each type of livestock product are shown in Table B. For the U.K., egg and poultry prices were calculated from the 1953–4 output (21); for other products, the prices are those used in compiling the 1953 annual index numbers for England and Wales (28). Danish prices were calculated from the 1953 output data (26), with the exception of the sheep products, whose prices are the writer's estimates.

APPENDIX TABLE A

Estimated feed inputs in 1000 acre-equivalents

	Belgium		Denmark		Netherlands		U.K.	
	1953	1954	1953	1954	1953	1954	1953	1954
	1000 acre-equivalents							
1. *Home-grown feed*								
Temporary grassland	274	200	1660	1641	89	82	5694	5920
Permanent grassland	1755	1814	937	954	3113	3111	14041	14286
Roots	175	173	964	973	146	143	876	824
Sugar-beet tops (root equivalent area)	32	32	32	30	37	42	91	96
Green crops	151	163	82	81	52	52	636	643
Potatoes	61	97	91	97	114	109	171	151
Total bulky foods	2448	2479	3766	3776	3551	3539	21,509	21,920
Cereals and pulses	765	749	2211	2469	891	963	5140	4936
Oil cakes and meals	10	6	8	6	10	5	5	3
Other industrial by-products and milling offals	391	352	161	163	151	179	850	846
Total concentrates	1166	1107	2380	2638	1052	1147	5995	5785
Total home-grown feed	3614	3586	6146	6414	4603	4686	27504	27705
2. *Imported feed* (including by-products of imported goods)								
Straw, hay and fodder-beet	5	4	—	—	—	—	1	3
Cereals and pulses	774	939	101	252	723	1193	3065	3206
Fish-, meat- and bone-meal* and high-protein compound feeds	9	8	414	519	58	80	232	289
Oil cakes and meals	176	211			286	396	1347	1367
Other industrial by-products and milling offals	142	199	52	56	108	135	913	1138
Other feedingstuffs	—	—	—	—	7	4	45	43
Total imported feed	1106	1361	567	827	1182	1808	5603	6046

*Includes meal made from home-produced livestock, since its quantity could not be estimated separately.

APPENDIX TABLE B

1953 Producers' prices per ton*

(Figures in brackets are the writer's estimates)

	U.K.	Denmark (at current exchange rates)
	£	£
Beef and veal	245·5**	254·6
Pork and bacon	321·3	239·1
Mutton and lamb	298·7	(309·7)
Poultry	275·3	288·8
Horse and other meat	(203·2)	190·0
Milk	35·0	19·1
Eggs	303·2	201·4
Wool	494·7	(494·7)

*Meat prices per ton deadweight.

**Based on the price per ton liveweight, assuming 54% killing-out proportion.

The particulars of quantities of livestock products were taken from the F.A.O. Yearbooks (10). However, the F.A.O. *wool* total includes wool from slaughterhouses, the value of which is included in the meat price. Therefore, in the present study, the U.K. quantity of wool is based on data given in the 1956 Agricultural Price Review white paper (29). For the other countries the F.A.O. wool figures were taken but, in view of the relatively small quantities involved, the resulting error is insignificant.

The value of livestock production at British prices is given in Table C, and at Danish prices in Table D. The quantities of milk and milk products fed to livestock were derived from national statistics. Milk products were valued at prices based on Ref. 1 and 24. The value of milk and milk products fed was deducted from the gross total production, and the area/output ratios quoted in the present article are based on the resulting "net" production.

APPENDIX TABLE C

Estimated value of livestock production at 1953 British prices

	Belgium		Denmark		Netherlands		U.K.	
	1953	1954	1953	1954	1953	1954	1953	1954
				£1000				
Beef and veal	37,938	41,563	43,013	45,913	41,805	45,188	147,646	176,160
Mutton and lamb	588	882	294	294	2,058	2,058	49,970	60,258
Pork and bacon	62,613	61,664	145,464	159,694	69,254	73,365	178,352	219,461
Poultry	4,606	4,606	6,503	6,774	4,634	6,585	28,206	27,664
Horse and other meat	2,560	3,340	3,720	4,160	1,560	2,820	4,000	1,680
Milk	121,921	126,025	185,486	186,037	201,247	202,213	370,109	378,490
Eggs	37,001	39,686	40,463	42,492	44,760	61,470	144,125	164,715
Wool	—	—	—	—	487	487	16,310	16,796
Gross total	267,227	277,766	424,943	445,364	365,805	394,186	938,718	1,045,224
Less milk and milk products fed to stock	9,647	10,136	25,019	25,687	15,722	15,851	27,741	27,932
Net total	257,850	267,630	399,924	419,677	350,083	378,335	910,977	1,017,292

APPENDIX TABLE D

Estimated value of livestock production at 1953 Danish prices

	Belgium		Denmark		Netherlands		U.K.	
	1953	1954	1953	1954	1953	1954	1953	1954
				£1000 at current exchange rates				
Beef and veal	39,339	43,098	44,601	47,608	43,348	46,856	153,097	182,664
Mutton and lamb	610	914	305	305	2,134	2,134	51,814	62,482
Pork and bacon	46,585	45,879	108,227	118,814	51,525	54,584	132,696	163,282
Poultry	4,832	4,832	6,822	7,106	4,860	6,907	29,589	29,021
Horse and other meat	2,394	3,123	3,478	3,890	1,459	2,637	3,740	1,571
Milk	66,553	68,793	101,251	101,552	109,854	110,382	202,030	206,605
Eggs	24,574	26,358	26,873	28,221	29,727	40,825	95,721	109,396
Wool	—	—	—	—	487	487	16,310	16,796
Gross total	184,887	192,997	291,557	307,496	243,394	264,812	684,997	771,817
Less milk and milk products fed to stock	6,514	6,894	21,182	21,850	10,553	10,604	15,806	15,997
Net total	178,373	186,103	270,375	285,646	232,841	254,208	669,191	755,820

3. *Influence of price system on area/output ratio*

Changing the price system used can affect the relationship between the different countries' or farms' feed/output ratios only if the ratios between prices of different products are altered. This can be illustrated by a simplified hypothetical example of two 100-acre farms. Let us assume that farm 'A' produces 48,000 gallons of milk and 2000 lb. of meat, and farm 'B'—35,000 gallons of milk and 5000 lb. of meat, and that neither farm uses any purchased feed. If milk is sold at 2s. per gallon, and meat at 2s. per lb., the output of farm 'A' will be worth £5000 and the ratio will be 20 acres per £1000 of output; for farm 'B', the output will be £4000 and the ratio 25 acres per £1000. In other words, farm 'B' will be using 25% more land per unit of output than farm 'A'. If we alter both prices in the same proportion and value milk at 3s. per gallon and meat at 3s. per lb., the output will become £7500 and £6000, and the area/output ratios, 13⅓ acres and 16⅔ acres per £1000; but the relationship between these ratios will remain unchanged, farm 'B' still requiring 25% more land per unit of output than farm 'A'.

Let us now assume a change in the price relationship, and value milk at 1s. 6d. per gallon and meat at 3s. per lb. Then the output of farm 'A' will be worth £3900, and that of farm 'B' £3375, giving the ratios of 25·6 and 29·6 acres per £1000. Now farm 'B' uses only 16% more land per unit than farm 'A'.

Naturally, the relationship between the area/output ratios in our hypothetical example would have remained unchanged despite the altered price relationship, if the ratio between the quantities of meat and milk had been identical on both farms. According to which products are 'favoured' by the price system adopted, the preponderance of certain products in a farm's or a country's output will influence the comparative position of that farm or country with regard to the area/output ratio.

For example, when the 1953 British prices are compared with the Danish prices for the same year, the British price system appears to favour eggs and milk in relation to meat. Ignoring mutton and lamb (since their average price could not be ascertained in Denmark, where there are very few sheep), and taking the price of meat (i.e. the simple average of the beef and veal, pigmeat and poultry prices) per ton in each country as 100, the indices of the other product prices per ton are:

	U.K.	*Denmark*
Milk	12·5	7·3
Eggs	108·0	77·2

It can be seen from Table E that the Netherlands, which have the largest milk and egg production in relation to the total livestock output, have the lowest area/output ratio among the four countries, when output is valued at British prices. With output valued at Danish prices, however, Denmark, which has the smallest milk- and egg-production in relation to the total output, has the lowest area/output ratio. Another result of this re-valuation of output is that the gap between the area/output ratio of Britain on the one hand, and the three continental countries on the other, becomes narrower.

APPENDIX TABLE E

Influence of the price system on the area/output ratio

	Belgium	Denmark	Netherlands	U.K.
1. *Output at 1953 British prices*				
Milk and eggs as percentage of total livestock production	% 58·0	% 49·2	% 65·7	% 52·0
Index of acre-equivalents per £1000 of livestock production	Index 53·1	Index 49·1	Index 48·6	Index 100·0
2. *Output at 1953 Danish prices*				
Milk and eggs as percentage of total livestock production	% 47·5	% 38·7	% 55·3	% 40·8
Index of acre-equivalents per £1000 of livestock production	Index 56·5	Index 53·5	Index 53·7	Index 100·0

INTER-VARIETY VARIATION IN RHODES GRASS (*CHLORIS GAYANA* KUNTH)

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The characters in 25 varieties of Rhodes grass introduced from Africa have been studied with a view to improving on Australian Commercial. Only the diploid Katambora and a tetraploid variety from Kenya appeared to possess a higher yield potential than Commercial. Sixty per cent of the varieties are tetraploid, the rest diploid. A degree of association occurred between the level of ploidy and some Rhodes grass characters.

Although Rhodes grass appears to be xenogamous, all the critical evidence points to an apomictic form of reproduction. Viable caryopses were extracted from harvested "seed" and the percentage of florets setting caryopses was low. Rhodes grass caryopses germinate fairly well and have a higher resistance than usual to irradiation by gamma rays.

INTRODUCTION

Rhodes grass (*Chloris gayana* Kunth) is an important pasture grass in a number of the summer rainfall areas of the world. Davies (6) outlined its history and establishment in Australia during the first decade of this century. Christian and Shaw (5) found a range of types between an erect early-flowering form and a laxer late-flowering one. They found also that the Queensland Commercial variety was predominantly erect but contained intergrading forms. In their pasture trials there was no yield difference between Commercial and a late leafy Kenya variety, C.P.I. 6585, under heavy grazing, but, with light grazing or none, 6585 outyielded Commercial. At present only the erect, early-flowering type (referred to in this paper as Commercial) is used in Australia and its success is due to its free seeding, ease of establishment, hardiness and frost tolerance. Its main deficiency is its tendency to produce flower stalks during most of the growing season, so reducing the percentage of leaf available to the grazing animal.

In recent years several promising varieties of Rhodes grass such as Katambora, Nzoia and Alego have been commercialized in Southern Rhodesia and Kenya and it appears that more will be developed in the future (2). Rhodes grass is native to Africa (1); Edwards and Bogdan (7) state that it is widely distributed in Kenya and that numerous ecotypes occur. Hartley and Williams (9) consider East Africa the centre for polymorphism of Rhodes grass.

In view of the importance of Rhodes grass to the tropical areas of Australia and the desire to improve on the Commercial variety, a concerted effort has been made over the last 10 years by the Plant Introduction Section of the C.S.I.R.O. Division of Plant Industry and by the Division of Tropical Pastures to introduce as many varieties as possible from Africa. The work described in this paper covers a study of some of the characters present in most of those available. In addition, a study of the breeding system of this grass was made to assess the possibility of improving it by genetic means.

ORIGIN, LEAF TYPE AND SOMATIC CHROMOSOME NUMBERS OF THE VARIETIES EXAMINED

The grasses examined are listed in Table 1. They are sufficiently different to be regarded as varieties. A high proportion of the varieties came from Kenya and Southern Rhodesia and a smaller number from the more humid tropics. Sixty per cent have a somatic chromosome number of 40 (all the coarse-leaved varieties, including the four tall and vigorous "giant" ones, and half the medium-leaved types). The rest of the medium-leaved, and all the fine-leaved, accessions have a somatic chromosome number of 20.

TABLE 1. **List of Rhodes grass varieties examined with their origin, leaf type, and somatic chromosome number**

C.P.I. No. (1)	Origin	Leaf type (2)	Somatic chromosome No. (3)	C.P.I. No. (1)	Origin	Leaf type (2)	Somatic chromosome No. (3)
6585	Kenya	M	40	16710	S. Rhodesia	C	40
12779	Uganda	C	40	16711	S. Rhodesia	C	40
13375	S. Rhodesia (Katambora)	F	20	16885	Uganda	M	40
				17753	Kenya	M	40
15371	Tanganyika	C	40	17754	Kenya	M	40
15510	Sudan	M	20	17755	Kenya	M	40
15692	Ethiopia	M	20	17757	Kenya	M	40
15892	Tanganyika	C	40	17759	Kenya	C	40
16042	Kenya (Alego)	M	40	17760	Kenya	M	20
16043	Kenya (Nzoia)	M	20	18021	S. Rhodesia (Katambora)	F	20
16059	Congo	C	40				
16144	Kenya	M	20	18708	S. Rhodesia (Katambora)	F	20
16256	South Africa	M	20				
16662	S. Rhodesia	M	20		Commercial	M	20
16663	S. Rhodesia	M	40				

(1) *In the Table:* C.P.I. No. = Commonwealth Plant Introduction Number. The introductions underlined are "Giant" varieties.

(2) *Leaf type:* F = fine; M = medium; and C = coarse, representing mean limits for the median widths of mature leaves of 3–4 mm., 4–6 mm., and 6–9 mm., respectively.

(3) *Somatic chromosome numbers*, determined mainly from pollen mother cells in appropriate aceto-carmine squashes.

FLOWERING PERIOD, PERSISTENCE AND FROST TOLERANCE

Ungrazed and heavily grazed plots of each of 24 varieties were established at the C.S.I.R.O. Pasture Research Station, Samford, on the outskirts of Brisbane, and at the Cooper Laboratory, Lawes, 50 miles west of Brisbane. The Samford plots were given 4 cwt. superphosphate per acre at establishment, but the Cooper plots were unfertilized. The plots were observed over the 1956–7 and 1957–8 seasons. The varieties in the ungrazed plots were rated monthly for degree of flowering in summer and autumn and twice for degree of frost tolerance after the occurrence of frosts in midwinter. The 1957 winter was the more severe; minimum grass temperatures at the Cooper Laboratory were between 22°F and 32°F on 30 occasions, and at Samford between 26°F and 32°F on 8. In the heavily grazed plots kept to a height of 4 to 6 inches, each variety was rated for stoloniferous development at the middle and end of the growing season. The results are summarized in Table 2.

TABLE 2. **Differentiation of varieties on flowering period, stoloniferous development and frost tolerance**

Period of flowering (ungrazed plots)			Degree of stoloniferous development (grazed plots)		
Nov.–May	Jan.–May	Apr. and May	Weak	Medium	Strong
Commercial	15510	6585	Commercial	15510	6585
16042	15692	12779	12779	16059	15692
16043	15892	15371	15371	16256	16144
16256	16663	16059	15892	16711	16710
17759	16710	16144	16042	17753	16885
17760	17753	16711	16043	17754	17757
	17757	16885	16663	17759	18021
	18021	17754	17755		18708
	18708	17755	17760		

In the above Table the results are the means of 2 sites and 2 seasons and the most frost-tolerant varieties are underlined.

Some differences in ratings occurred between seasons and between sites, but these were not great enough to prevent the placing of each variety into a definite group. There was some negative correlation between length of flowering period and degree of stoloniferous development. Those varieties listed in Table 2 as possessing strong stoloniferous development were the most persistent under grazing when judged on their ability to maintain a dense ground cover. The most frost tolerant varieties were Commercial, 16043 and 17760, all 20-chromosome types. Those with medium frost tolerance were the 20-chromosome types 13375, 16256, 16662, 18021 and 18708; all other varieties had a low tolerance to frost.

YIELDING ABILITY

Ten of the most promising varieties and the Commercial were each established from seedlings in plots arranged in randomized blocks at three sites. Two of the sites were at the Cooper Laboratory, one being on a ridge having poor solodic soil and the other on a flat of rich black earth. The third site was on a meadow podsol of medium quality at Samford. The soil at the experimental sites was fallowed for 6 months before planting. Each plot was 40 links × 35 links and contained 56 plants. At the Cooper Laboratory each variety was replicated 6 times and at Samford 12. The plots at Samford and on the Cooper Ridge were given 4 cwt. of superphosphate per acre at establishment, whereas the Cooper Flat plots were unfertilized.

The experiments were planted in February 1958 and were heavily grazed and mown at the end of July. Yielding ability of each variety was obtained from 2 sample cuts, one towards the end of November 1958, representing the spring growth, and one early in April 1959, representing summer growth. Each sample consisted of a 3 ft. cut with a mower, taken at random along the length of a plot. After sampling, the plots were heavily grazed by sheep at the Cooper Laboratory and by cattle at Samford. Any standing material was then mowed off.

The mean summer yields given in Table 3 were significantly greater than their corresponding spring yields, except in 17757 and 16144 on the Cooper Ridge. Also totals of the mean yields for spring and summer of all the varieties were significantly highest on the Cooper Flat and lowest on the Cooper Ridge. These yields are related to the known soil fertility at the three sites.

Significantly higher yields than that of Commercial Rhodes grass were obtained with 17757 in spring on the Cooper Ridge and in

TABLE 3. Mean yields of the spring and summer cuts from the different Rhodes grass varieties in lb. of dry matter per acre

	Cooper Ridge			Samford			Cooper Flat		
C.P.I.	Spring	Summer	Position (Total)	Spring	Summer	Position (Total)	Spring	Summer	Position (Total)
17757	577*	666	2	1289	2785*	4	2364	8147*	1
16885	—	—	—	—	—	—	3234	6796	2
16144	282	308	10	828	2415	10	3272	6372	3
18021	306	903	3	1076	3300*	2	2384	6727	4
18708	195	861	4	1046	3536*	1	1741	7326	5
13375	158	335	11	618	3293*	5	1572	7058	6
16710	313	561	7	1002	2728*	6	2266	6345	7
Commercial	272	586	8	1322	2114	8	2389	6169	8
15692	346	542	5	1130	2027	11	2402	5930	9
16256	196	681	6	1077	2349	9	2395	5773	10
16043	403	885	1	1615	2460	3	2924	4462	11
6585	306	424	9	798	2820*	7	2108	5176	12
Min. diff. for significance at $P<0{\cdot}05$	148	421		412	588		1246	1688	

Totals of mean yields of varieties 18021 and 18708 at Samford (underlined) and the mean yields marked with an asterisk were significantly different from Commercial at the 5% level.

summer at Samford and on the Cooper Flat. Summer yields of 18708, 18021, 13375, 6585 and 16710 were significantly greater than Commercial at Samford. Also, at this site, the totals of the mean yields of 18708 and 18021 for spring and summer were significantly higher than Commercial.

After each grazing some measure of the palatability of the different varieties was obtained by rating all plots for the amount of forage eaten. It was apparent that on this basis only one variety, 16144 from Kenya, was consistently more palatable than the rest.

MODE OF REPRODUCTION

Flowering and seed setting. Bogdan (2) and (3) examined the flowering habits of Rhodes grass and concluded that it is essentially a xenogamous and allogamous species. Brown and Emery (4) inferred that diploid varieties of Rhodes grass are sexual and that tetraploid are apomictic.

A similar mode of flowering to that described by Bogdan (3) was observed in the different Rhodes grass varieties at both Samford and the Cooper Laboratory. On clear sunny days they flowered between noon and 4 p.m. The stigmas were extruded first, followed a few minutes later by the anthers, which then rapidly dehisced. To assess the effect of selfing on seed setting, three recently emerged inflorescences on different plants in each of 18 varieties at Samford and the Cooper Laboratory were enclosed in porous cellophane bags at their peak of flowering. These and similar open-pollinated inflorescences were harvested when ripe and the total length of spike, number of spikelets and florets, and number of caryopses per inflorescence were determined. The number of spikelets per cm. of spike varied from 7·06 to 9·92, with a mean of 8·59.

The caryopses were separated by soaking the florets from a ripe inflorescence for 1 to 2 minutes in concentrated sulphuric acid and washing in water, which was filtered off through organdie pads. Although it retains the caryopses, this method destroys their germination. There were only slight differences between seed-setting at the Samford and Cooper Laboratory sites and the mean values for these are summarized in Table 4. In all but two varieties the percentages of florets which set seed after selfing were significantly less than under conditions of open pollination.

TABLE 4. Caryopses set in 18 varieties of Rhodes grass

No. of varieties	Percentage of florets setting caryopses	
	Selfed	Open-pollinated
9	0·2–0·6	1·9– 5·2
7	1·1–4·0	8·3–13·3
C.P.I. 17760	10·9	9·7
C.P.I. 16042	20·4	13·7

There was a correspondence between the seed-setting in selfed and open-pollinated florets in any one variety so that it was possible to divide the different varieties into two main groups. In the diploid 17760 and tetraploid 16042 seed-setting following selfing was higher than that in open-pollinated inflorescences.

Degree of compatibility. The type of flowering and reduction in seed-setting following selfing indicated a cross-pollinating habit and self-incompatibility in Rhodes grass, although the results with 17760 and 16042 suggested that these varieties at least were self-compatible. The degree of compatibility in inflorescences of 10 different varieties of Rhodes grass, both selfed and open-pollinated in the field and collected at various times after anthesis, was studied by observing the extent of pollen-tube growth. Stigmas and ovaries were dissected from the florets, bleached in a solution of sodium hypochlorite and then stained with aqueous lacmoid, as described in the technique of Wilson and Brown (12).

In selfed and open-pollinated florets the mean percentages of stigmas with penetrating pollen tubes were 40% and 35% respectively. Pollen-tube growth into the stigmatic branches is initiated soon after anthesis and two hours after anthesis a number of tubes are present in the ovary. When plants were grown in the glasshouse at the height of the monsoonal season, slow and defective pollen-tube growth was observed, which occurred whether the plants were selfed or not.

Lack of intra-variety variation. All the Rhodes grass varieties mentioned in this paper were first grown adjacent to each other in the plant introduction nursery and in most cases had been grown there several times from seed. Thus no attempt was made to isolate the varieties and the available seed had every chance of a cross-fertilized origin.

The yield trials at the Samford and Cooper Laboratory sites were planted with seedlings raised from the nursery seed. Over 1300 single plants were transplanted at a 5-link spacing in the different plots of each variety. These were observed until the plants merged into uniform plots of grass. No obvious plant-to-plant variations in the morphological characters of any variety were noted. After three seasons the plots of any one variety were distinct and uniform for the characters associated with the particular variety. In view of Christian and Shaw's (5) observations on Commercial, it is of interest to note that collections of this from naturalized stands in different areas of Queensland gave morphologically similar and uniform progenies.

Cytological features. Although Rhodes grass possesses features characteristic of a xenogamous habit, an apomictic mode of reproduction could be involved, as suggested by Brown and Emery (4) for tetraploid varieties of this species. In order to study development of the megaspore mother cell, embryo sac and embryo, inflorescences of the diploid Commercial variety and the tetraploid 17757 were fixed prior to and at anthesis, and at hourly intervals up to 24 hours after anthesis. The material was embedded in wax, using Johansen's (10) tertiary butyl alcohol method, and then stained with Johansen's (10) safraninfast green technique. In both these varieties an 8-nucleate embryo sac originated normally from the megaspore mother cell, which began to divide soon after division of the pollen mother cells. Attempts to determine chromosome numbers during division of the megaspore mother cell were unsuccessful.

The pattern of development was similar in 17757 and the Commercial variety. A large number of sections was examined and although male gametes were often present in the vicinity of the egg cell 9 to 17 hours after anthesis, fusion was never observed. The antipodals degenerate early, some 8 hours after anthesis, and the synergids 22 hours after, when the egg cell begins to divide. The usual fusion of polar nuclei does not occur and about 14 hours after anthesis the polar nuclei separate to each side of the embryo sac and begin to divide, forming two separate groups of endosperm cells. There was no indication of fusion between male gametes and polar nuclei. Twenty-two hours after anthesis each endosperm group reaches about a 30-cell stage, when active division of the egg cell begins. Thus there is a lag of 8 hours between the first division of the polar nuclei and the initiation of embryo development. Normally endosperm and egg cell divisions are simultaneous, or closely follow each other. The two groups of endosperm finally merge, while typical growth of the embryo occurs.

SEED PRODUCTION AND GERMINATION AND EFFECT OF IRRADIATION ON SEED

Viable caryopses were extracted from the harvested "seed" (spikelets and glumes) of Rhodes grass by beating 0·5 g. samples in a Waring blender with 200 ml. of water for two minutes. Glumes and pieces of rachis were poured off and the caryopses at the bottom of the container collected by filtering through cloth.

Duplicate 0·5 g. samples of 1957 and 1958 "seed" of a number of varieties were extracted and the number of caryopses per sample determined, after which the caryopses were germinated on moist filter paper in petri dishes. Further duplicate 0·5 g. lots of untreated "seed" were sown in flats of soil in the glasshouse and the seedlings which had emerged after three weeks were counted, the germination obtained being similar to that of the extracted caryopses. Further samples of 1958 "seed" of four varieties were treated at the University of New South Wales with dosages of gamma rays from Co^{60} ranging from 10,000r to 150,000r. Duplicate 0·5 g. samples of the irradiated "seed" from each variety and each dose were sown in flats of soil in the

TABLE 5. Effect of season and irradiation on germination of caryopses in the "seed" of 6 varieties of Rhodes grass

	No. of caryopses/0·5 g.		% germination of caryopses				
	1957	1958	1957	1958	1958 "seed" irradiated		
Variety	"seed"	"seed"	"seed"	"seed"	60,000r	107,000r	150,000r
15692	399	756	37·1	86·5	43·2	21·6	7·8
Commercial	420	772	51·6	73·0	30·1	20·3	6·5
16144	215	527	43·4	66·6	55·0	43·1	11·0
17757	659	639	25·1	54·1	55·8	35·7	23·1
18021	259	531	48·2	49·7	—	—	—
16885	370	219	Nil	42·9	—	—	—

glasshouse and seedling emergence was determined. Results from six of the varieties used in these various experiments are summarized in Table 5. Only data from the 60,000r, 107,000r and 150,000r irradiation treatments are included, as these were the most critical.

Number of caryopses and their germination were influenced by both variety and season, the "seed" from the 1958 season tending to be better than that from 1957, although an ageing effect must be allowed for. Lack of germination in the 1957 seed of 16885 was of interest, as the caryopses appeared normal and none of the dormancy-breaking treatments tried, including soaking in a 2% solution of potassium nitrate, was successful.

Rhodes grass "seed" possesses a high resistance to irradiation and the results indicate differences between varieties in this respect. A dose of 107,000r, although it reduced germination, did not cause a reduction in vigour of the resultant seedlings. Doses above 107,000r reduced germination and survival markedly.

DISCUSSION

A Rhodes grass variety which produces a high proportion of leaf during the summer growing period and then seeds only in the autumn would be an improvement on Commercial. One such variety is No. 6585, which was compared with Commercial by Christian and Shaw (5) but was found to have no yield advantage over it under heavy grazing. Table 3 confirms their results but demonstrates that the Katambora varieties 18021 and 18708 could have a significant yield advantage over Commercial in environments similar to that represented by Samford. As shown in Table 2, the Katambora varieties have a more restricted flowering period than Commercial, but they are strongly stoloniferous and appear to be more persistent under heavy grazing. In addition, they have some frost tolerance. The tetraploid 17757, although lacking frost tolerance, is of interest because of its inherently higher yielding ability on all three soil types. The results in Tables 2 and 3 demonstrate the difficulties in finding an improvement over the Commercial variety with its hardiness and frost tolerance. Two diploid strains similar to it are 16043 (Nzoia) and 17760. It is possible that a very palatable variety like 16144 may have an advantage over Commercial, particularly under fertile soil conditions.

The presence of two levels of ploidy in Rhodes grass has already been shown by Moffett (11) and Brown and Emery (4), so the fact that 60% of the varieties examined in this study are tetraploid (vide Table 1) is not unexpected. There is some association between chromosome number and various characters. Thus all coarse-leaved varieties listed in Table 1 are tetraploid and fine-leaved ones diploid, medium-leaved being diploid or tetraploid. Of the 11 diploid varieties, only 3 did not possess medium to good frost tolerance, while all tetraploids were quite frost-susceptible. With the exception of 16144 all the late-flowering varieties listed in Table 2 are tetraploid. The results indicate a tendency for diploids to be hardier than tetraploids.

The mode of flowering and the results from selfing experiments summarized in Table 4 tend to indicate a xenogamous habit in Rhodes grass. However, the various varieties, differing widely in morphological and other characters, were grown in close proximity under conditions which would allow maximum cross-pollination, yet the seed from them produced apparently uniform plant populations. This evidence, and the low set of caryopses, strongly suggest an apomictic form of reproduction already postulated by Brown and Emery (4) for the tetraploid varieties. Apparently the intermediate forms noted previously in Commercial by Christian and Shaw (5) were from admixture and have been lost owing to competition from the early erect type.

The cytological and embryological work reported in the present paper was only partially successful in proving that Rhodes grass reproduced by apomixis. It did show the development of similar 8-nucleate embryo sacs in the diploid and tetraploid varieties examined. No 4-nucleate embryo sacs, as described by Brown and Emery (4) for tetraploid varieties of Rhodes grass, were found. However, the pattern of embryo and endosperm development is unusual, and both processes are delayed considerably. Endosperm is formed from polar nuclei which do not fuse and it begins to develop 8 hours before the egg cell starts to divide. It is apparent that an unusual and similar type of reproduction occurs in both diploid and tetraploid varieties and that further work is required to elucidate it properly.

Since Rhodes grass appears to be apomictic, the plant breeder is restricted in the techniques which can be used to induce variability for the processes of selection. It is quite possible that the 40-chromosome types are autotetraploids, as suggested by Moffett (11). On this basis, the doubling of the chromosomes of the diploids with colchicine would be worth while. Also induction of mutations by irradiation of seed should be possible. The results given in Table 5 show that the caryopses of Rhodes grass germinate fairly well and possess a relatively high resistance to irradiation, in fact much higher than usual (see Gustaffson (8)). The evidence indicates that the critical dosage for the production of mutants in the M_1 generation may be around 107,000r.

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STUDIES IN CALF MANAGEMENT

III. THE REARING OF AUTUMN-BORN CALVES AT PASTURE

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Calves born in late September to early October in 1956, 1957 and 1958 were reared at pasture. They were fed milk substitute, supplemented in some cases with concentrate feeding-stuffs.

The losses due to outdoor rearing were low, and calves made satisfactory gains in weight. By rearing at pasture, a considerable saving was effected in the weight of concentrates and hay consumed, while no marked response to the feeding of these supplements before weaning was found. Animals born in the autumn of 1957 and reared on this system reached 10 cwt. in less than 24 months.

INTRODUCTION

A large proportion of beef-cross calves from dairy herds in the United Kingdom are born in the autumn and it is at this time that such calves are most plentiful in the markets. If these young animals could be satisfactorily reared at low cost during their first winter, the prospects of making a reasonable profit from the beef product would be enhanced. It has already been shown (1) that it is possible to dispense with calf meal and hay by rearing calves at pasture in the spring. The autumn-born animal reared outdoors must, however, expect poorer quality grass than its spring counterpart. The weather may at first favour the calf born in September or October, and it is possible that it will make rapid progress and be able to withstand the more severe conditions of winter.

The aims of the three small-scale trials reported below were to see if calves reared outdoors could withstand the weather conditions of autumn and winter, and to study the need for supplementary feeding. Small numbers of animals were used in these trials, but larger groups are now being reared and their progress will be reported later.

EXPERIMENT 1, 1956–7

On 29 September 1956 twenty Hereford colour-marked steer calves, 7 to 14 days old, were allocated at random to the following treatments:

(A) Multiple-suckling indoors. Four calves suckled a freshly-calved cow and received calf meal and hay.
(B) Bucket-feeding indoors. Calves received milk substitute and were offered calf meal and hay similar to (A).
(C) Early-weaning indoors. These animals were reared on milk substitute, commercial calf pencils and hay.
(D) Bucket-feeding at pasture. Milk substitute and hay were offered but no calf meal. Ground oats were provided after the thirteenth week.
(E) Early-weaning at pasture. Calves were reared on similar rations to those in (C) but also had access to grass.

The rearing period lasted for 16 weeks, although groups C and E were weaned at the end of the fourth week. The composition of the feeding-stuffs and the rations used in this trial are shown in Table 1.

The swards grazed by groups D and E were composed of lucerne and grass in alternate rows. Different grass species were sown singly and with lucerne and the varieties used were S23 perennial ryegrass, S37 cocksfoot and S48 timothy. The pasture had been twice cut for silage earlier in the season and then rested for foggage production from early August. At the beginning of the trial the lucerne was green and the calves found the leaves acceptable, but by the end of October frost had killed off most of the foliage and it was ignored by the stock. Approximately 6 acres of pasture

TABLE 1. **Feedingstuffs used during 1956-7 trial**

	Milk substitute	Calf meal	Calf pencils	Oats	Hay
Groups	B, C, D, E	A, B, D	C, E	D	A, B, C, D, E
Composition	Dried skim-milk powder 80 parts Whole oat flour 20 parts Dried yeast 1·5 parts Vitamin A 2000 I.U./calf/day Vitamin D 500 I.U./calf/day	Ground oats 50 parts Dried grass meal 20 parts Flaked maize 10 parts Fish meal 10 parts Minerals 2 parts			
Crude protein (%)	33·2	24·1	22·2	15·1	8·1
Normal-acid fibre (%)	3·1	16·0	20·3	17·5	38·1
Rate of feeding	Starting at 1 lb. and increasing to 1·5 lb. per day by twenty-first day. Reduced during fourth week for groups C and E, and during fifteenth week for B and D	Up to a maximum of 4 lb. per day	Up to a maximum of 6 lb. per day	Up to a maximum of 4 lb. per day offered from 28 Dec. to 17 Jan.	*Ad libitum*

were used during the winter. Initially it was divided into strips for each group of calves and block-grazed with front and back electric fences, moved every 5 to 6 days. After the area had been grazed once the fences were removed.

The site of rearing was at an altitude of some 300 feet on an outcrop of the Chiltern Hills. Apart from a low copse to the south-east there was no shelter from hedges and it was typical of large fields on top of chalk lands. Because of the exposed situation each group of calves was given a round galvanized iron pig ark for a shelter.

On completion of the rearing period (17 January 1957) the calves which had been reared indoors were run together in groups and each fed daily 4 lb. calf meal, 3 lb. hay and silage *ad libitum*. They were kept in loose boxes until 30 March when they were put out to pasture during the day, before going out permanently on 2 April. Calves reared outdoors were offered a similar ration but were allowed to graze over the pasture on which they were reared. As from 2 April all animals grazed together throughout the summer and autumn.

Results

The calves reared outdoors did not appear to suffer any ill effects from the rigorous conditions to which they were exposed. There was no scouring among these animals neither were there any chills, but two calves reared indoors on the bucket (Group B) developed slight chills early in the trial. On the seventeenth day one calf in group D developed bloat after a milk feed. This condition was also noticed in several indoor calves shortly afterwards and it tended to reappear after each meal. Most calves gradually improved, but on the thirty-fifth day the calf in Group D was found dead and post-mortem examination indicated that death had resulted from bloat.

The average weights of feeding-stuffs consumed during the rearing period, apart from herbage, are shown in Table 2. It will be seen that there was a substantial saving in the weight of calf meal by rearing calves on milk substitute and grass. Early weaning at pasture also reduced the consumption of calf 'pencils', and the intake of hay was lower outdoors. Another point of interest was that calves receiving a liberal quantity of calf pencils at pasture ate noticeably less herbage than those offered no supplement.

After weaning all groups consumed 304 lb. calf meal and approximately 230 lb. hay per calf up to 2 April. No close check was kept on the weight of silage used, but it was apparent that the animals outdoors ate slightly more than those kept indoors.

The average live-weight gains of the different

TABLE 2. **Average food consumption per calf during 16-week experimental period (1956-7)**

	Multiple-suckled A	Bucket-fed indoors B	Early-weaned indoors C	Bucket-fed on pasture D	Early-weaned on pasture E
Whole milk (gal. estimated)	168	—	—	—	—
Milk substitute (lb. powder)	—	155	32	155	32
Calf meal (lb.)	273	205	—	—	—
Calf pencils (lb.)	—	—	415	—	278
Oats (lb.)	—	—	—	49	—
Hay (lb.)	135	153	138	80	31

TABLE 3. **Average live weights of calves during first 12 months (1956-7)**

	Multiple suckled A lb.	Bucket-fed indoors B lb.	Early-weaned indoors C lb.	Bucket-fed on pasture D lb.	Early-weaned on pasture E lb.
Weight at 29 Sept. 1956	106	111	112	113	106
Weight at 17 Jan. 1957	295	242	258	220	278
Average daily live-weight gain to 17.1.57	1·69	1·17	1·30	0·96	1·54
Weight at 28 March 1957	400	308	323	348	364
Weight at 5 Sept. 1957	653	543	573	642	599
Average daily live-weight gain 29.9.56 to 5.9.57	1·61	1·27	1·36	1·56	1·45

groups are shown in Table 3. During the rearing period the best gains were made by the suckled calves (1·69 lb. per day) and the poorest (0·96 lb. per day) by the calves receiving milk substitute for 16 weeks at pasture. Calves reared indoors on the bucket were only a little better at 1·17 lb. per day. This was probably due to intake of nutrients rather than better shelter. Where adequate herbage of good quality was provided (Group E), live-weight gains of 1·54 lb. per day were superior to those of similar animals kept indoors (Group C, 1·30 lb. per day) although each calf in the latter group consumed 137 lb. more calf pencils and 101 lb. more hay.

After weaning, Group D, which had been reared outdoors with only a small supplement of oats, started to improve rapidly. By early September these animals were heavier than all but the suckled groups and weighed nearly 6 cwt.

EXPERIMENT 2, 1957–8

On 5 October 1957 three groups, each of four Hereford-cross steer calves, were turned out to pasture when 7 to 14 days old. Each group was given a daily ration of milk substitute similar to that used in the previous trial, but for a period of only 12 weeks. Apart from this,

Group (F) received no food other than herbage;

(G) received, in addition to herbage, a supplement of coarsely-ground oats up to a maximum of 4 lb. per calf per day;

(H) received herbage and up to 4 lb. calf meal (as used in the previous trial).

The pasture used for rearing was composed of lucerne and S50 timothy in alternate rows. It had been managed in the same way as that used for the previous trial, having been shut up in late July after two silage crops had been taken. The site was approximately 300 yards to the east of that used in 1956–7. It had low copses on the south and north sides, but a gap of some 50 yards between these tended to 'funnel' winds from the easterly and westerly quarters. In view of the less exposed position, however, no shelter was provided for the calves. After weaning they were moved to a more exposed field, where again no shelter was provided. During this period and until grass resumed growth in mid-April, each calf received daily 4 lb. oats/barley, 3 lb. hay and silage *ad libitum*. From mid-April grass formed the entire diet until the animals were slaughtered on 10 September 1959. Only in March 1959 was grass silage on offer; at no time were concentrates or hay used.

Results

The health of the calves was less satisfactory than in the previous trial, but it is difficult to assess how far this was due to the effects of outdoor rearing or to other factors. Generally, the animals were in poorer condition when purchased and two contemporaries reared on a multiple-suckling system indoors died from bacterial scour. Of the calves reared at pasture, one (E.16) in group G and another (E.19) in Group H, made very poor progress, with periods of scouring and general unthriftiness, and it was not until towards the end of the trial that they started to recover.

Further trouble was experienced from bloat. It again appeared to be associated with milk substitute feeding and one calf was lost (Group G). Another calf (E.12 in Group F) suffered in varying degrees after each feed and on two occasions it was necessary to puncture the rumen and express gas which had collected. This animal made very poor progress and was discarded after the winter period.

The second loss was almost certainly not associated with rearing at pasture. Powdered minerals were provided in an open trough at the start of the trial and it was noticed that several calves were spending prolonged periods consuming these minerals. After two days severe scouring occurred in these animals and the minerals were removed. Recovery was rapid by all but one calf which was slaughtered on the fifteenth day. Post-mortem examination showed ulceration of the abomasum and the small and large intestines. It seems very probable that this calf suffered in some way from an excessive intake of minerals.

The remaining seven calves made useful live-weight gains throughout the trial period (see Table 4), but there appeared to be little advantage from feeding calf meal or oat supplement. The average daily gain of all calves, except that suffering from chronic bloat, was 1·33 lb. over the 12-week period.

By the time the animals were 12 months old the average weight was 710 lb. At the end of the following winter period, during which they had each consumed about 1 ton of silage as the only supplementary feed to foggage, their weight showed little change. However, by the time they were ready for slaughter in early September 1959 the average weight was 1168 lb. and all but two carcasses were graded A.

EXPERIMENT 3, 1958–9

In this trial Friesian calves were used for the first time. Six half sibs were collected from local farms when 4 to 7 days old, and together with six Hereford-cross calves, 10 to 14 days old, were allocated in equal numbers to three groups on 22 September 1958.

TABLE 4. Average live weights of calves born in the autumn of 1957

Group	No supplement			Oat supplement			Calf-meal supplement			
	F			G			H			
Calf	E12*	E14	E20	E4	E16	E17	E5	E13	E15	E19**
	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.
Weight at 5 Oct. 1957	97	93	110	105	92	104	105	102	103	91
Weight at 27 Dec. 1957	163	216	241	210	156	214	265	200	223	166
Average daily live-weight gain to 27 Dec. 1957	0·79	1·46	1·56	1·25	0·76	1·31	1·90	1·17	1·43	0·89
Weight at 1 Oct. 1958	—	726	718	701	611	683	793	722	725	—
Weight at 31 March 1959	—	767	658	695	588	666	778	713	701	—
Weight at 10 Sept. 1959	—	1226	1188	1069	1041	1161	1274	1206	1178	—
Average daily live-weight gain 5.10.57 to 10.9.59	—	1·61	1·53	1·37	1·35	1·50	1·66	1·57	1·52	—

* This calf suffered from bloat during rearing period and was discarded at weaning

** This calf was discarded at weaning

Group (I) received milk substitute and grass;
(J) was offered in addition a low-protein meal;
(K) received a meal supplement of similar energy value to that used for J, but of higher protein content.

In an attempt to eliminate bloat, dried buttermilk powder was used instead of the previous mixture of dried skim milk powder and oat flour, and feeding was carried out with 'Calfeteria' tubes and teats. The quantity of buttermilk powder used was similar to that of the milk substitute and it was again mixed at the rate of 1 lb. to 1 gallon of warm water. Individual feeding was not practical either for the liquid or meal rations but each group was kept separate and the meal supplements were fed at the same level up to a limit of 4 lb. per calf per day.

For the first month grazing took place on a small sheltered paddock, the herbage of which was leafy but rather long, having been rested from early August. Later the calves were moved to a better quality ryegrass/white clover sward. This site was very exposed to north and north-easterly winds, although there was a copse along the western edge. Furthermore the underlying soil was clay. The three groups grazed in separate strips, which were subdivided, until weaned, when they had access to the entire 2-acre paddock. No shelter was provided but after weaning a straw pad was built up in one corner of the paddock to provide dry-lying.

Weaning took place after 9 weeks and thereafter each calf was offered daily 4 lb. oats/barley, 3 lb. hay and silage *ad libitum*. On 12 April 1959 the cereal ration was withdrawn and by 16 April the animals were on spring grass without supplementary feeding.

Results

During the first few weeks of this trial the calves were exposed to prolonged periods of heavy rain—4·8 in. fell in the first 21 days. This was followed by persistent fog. Under these conditions and with little sunshine to help dry their coats, the calves were severely tested. While the majority, the Hereford in particular, did not appear distressed, one Friesian died on the twenty-second day. Post-mortem examination showed no pathological lesions and it must be presumed that exposure was responsible for death. This calf was replaced on 16 October by another which made normal progress. The other Friesian in the same group (I) made very poor progress throughout the trial but this could have been accounted for by a reluctance to take its buttermilk ration. It made a good recovery after weaning when it was provided with the oat/barley mixture.

Apart from these two animals, the remainder made very useful live-weight gains (see Table 5) during the pre-weaning period. There appeared to be only a slight advantage again from feeding meal supplements. After weaning, average gains in excess of 1 lb. per day continued until supplementary feeding ceased. During the grazing season gains were generally not quite so high as in previous trials but this may have been due to a dry season and shortage of herbage.

TABLE 5. Average live weights of calves during first 12 months (1958-9)

	No supplement I		Low-protein meal J		High-protein meal K	
	Hereford lb.	Friesian* lb.	Hereford lb.	Friesian lb.	Hereford lb.	Friesian lb.
Weight at 22 Sept. 1958	106	92	92	100	95	96
Weight at 27 Nov. 1958	201	120	190	193	203	196
Average daily live-weight gain to 27.11.58	1·51	0·44	1·56	1·48	1·71	1·59
Weight at 10 April, 1959	381	305	352	314	384	338
Weight at 16 Sept. 1959	641	548	608	556	636	586
Average daily live-weight gain 22.9.58 to 16.9.59	1·49	1·27	1·43	1·27	1·50	1·36

* Figures for one calf only

TABLE 6. Weather conditions during the three trials*

	October			November			December			January			February		
	1956	1957	1958	1956	1957	1958	1956	1957	1958	1957	1958	1959	1957	1958	1959
Mean minimum temperature (°F)	38·5	39·6	44·7	31·4	34·7	39·1	34·5	28·5	36·0	36·2	33·3	29·4	36·0	34·8	33·5
Lowest minimum temperature (°F)	26	26	35	14	20	29	22	15	29	26	17	19	27	26	23
Highest minimum temperature (°F)	53	52	54	45	46	50	46	41	50	52	48	45	50	51	44
Total rainfall (in.)	1·54	1·94	2·97	0·53	2·27	2·65	3·66	2·19	3·14	1·95	2·93	2·82	3·50	2·80	0·06
Number of wet days (i.e. >0·04 in.)	12	12	15	6	7	10	14	11	15	13	10	11	16	13	—
Number of days with snow	—	—	—	—	—	—	3	—	—	1	—	—	—	5	—
Average daily sunshine (hr.)	3·36	2·77	2·84	2·08	2·17	1·31	0·27	1·30	0·87	1·48	1·38	2·39	2·39	1·61	2·03

*Recorded at The Grassland Research Institute, Hurley

DISCUSSION

The principal aim of these small-scale trials was to see if young calves purchased in the autumn could survive when reared at pasture. Out of a total of thirty-two calves reared outdoors four died, and of these losses all but one could be attributed to extraneous circumstances. In addition, three calves failed to make satisfactory gains during the rearing period; two of these made a good recovery. Considering the risks of infection in purchased calves, the losses involved in these trials are not excessive.

Survival probably depends on the severity of the climate to which the calf is exposed. Table 6 shows that during three seasons the animals had to withstand a wide variation of temperature and rainfall. Despite the lack of shelter, the only time when calves appeared slightly distressed was when heavy rain was accompanied by strong winds. No detailed study was made of the need for shelter but the impression was gained that a dry bed was more desirable than protection from the cold. The calves rapidly grew shaggy coats and did not appear worried by low temperatures.

With animals being reared for beef it is important that growth and development should not be severely checked, particularly in the calf stage. In this respect, the live-weight gains of calves reared at pasture were generally satisfactory. An average gain of approximately 1·5 lb. per day compares favourably with that obtained under other systems of rearing, except possibly single-suckling or those involving the heavy feeding of high-quality concentrates. Furthermore, this progress was maintained without any check in the following spring, and, as was shown by the Herefords in the second trial, it was possible, without any more concentrate feeding-stuffs, to get these animals to weigh over 10 cwt. before they were 2 years old.

The second aim of these trials was to assess the need for supplementary feeding during the pre-weaning period. The results obtained indicated little advantage from this, but it has been shown elsewhere (2) that there may be some response to an energy supplement. The recovery after weaning by non-supplemented calves, however, makes it doubtful if this can be justified economically.

It was shown clearly in the first trial that a considerable saving in feeding costs can be made by using pasture in the autumn. The costs of labour involved are, however, more difficult to assess. There is no doubt that the carting of milk to the field is an unfavourable aspect of outdoor rearing and, although it is offset to some degree by the absence of charges for bedding and cleaning-out, the shorter the period during which it is necessary the greater will be the saving. It is significant, therefore, that this period was reduced from 16 weeks in the first trial to 9 weeks in the third without apparent harm to the calves. It is not possible to say what further reduction could be made without a corresponding rise in the consumption of concentrates.

In considering the application of pasture rearing of autumn-born calves, three points must be taken into account. First is the pasture. No information is at present available on the type of sward most suitable for this system. What is important is that the herbage should be free from parasitic husk worm infestation when the calves are introduced. This means a rest of several months from grazing by infested cattle, and the most convenient arrangement found at Hurley has been to use a field that has been cut for silage in May and July–August and put up for foggage. Second is the site for rearing. If some natural shelter is available, this is an advantage, but a field fairly close to the dairy is important if long hauls of milk are to be avoided. On some farms the soil type may limit the application of the system but, given a dense sward or alternate rows of lucerne and grass, calves do not seem to cause any serious damage to the sward even on a clay soil. Third is the tending of the calves. In bad weather feeding calves outdoors is not a pleasant job and, unless some quick and simple method of supplying the milk can be devised, this may hinder the adoption of pasture rearing in the autumn. Nevertheless, this system has much to recommend it, for it has been shown that healthy calves can survive even in bad weather and can make useful progress on a diet where grass largely replaces concentrate feeding-stuffs.

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THE EFFECT OF DRILL WIDTH ON THE SEED PRODUCTIVITY OF LEAFY VARIETIES OF THREE GRASS SPECIES

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Three leafy grass varieties, S215 meadow fescue, S37 cocksfoot and S51 timothy, were subjected to four drill spacings of 6, 15, 24 and 36 in. under two levels of nitrogen application. Over three harvest years, meadow fescue gave better seed yields with 6- and 15-in. drill spacings. Cocksfoot gave very similar yields from 15-, 24- and 36-in. drills but a significantly reduced yield from 6-in. spaced drills. Timothy produced significantly higher yields at the 24-in. spacing.

The three varieties showed a significant response to nitrogen application.

Aphids seriously affected the vegetative growth of meadow fescue and timothy at the wider spacings, but the 6-in. drills in both species remained relatively free of aphid attack, as also did the cocksfoot block.

INTRODUCTION

A study of the seed crop inspection reports of Aberystwyth grass varieties reveals a considerable lack of uniformity in the cultural techniques employed, even between two adjoining farms growing the same variety. Factors such as seed rate, drill width, quantity and time of fertilizer application, appear to vary widely and all these may be expected to have a profound effect on the resultant seed yield. Practical considerations, as well as local conditions of soil and climate, determine the method of growing in a given instance. Nevertheless experimental evidence is accumulating which indicates that, even under widely different conditions, seed yields are enhanced by following a more uniform pattern of husbandry for individual species, or varieties within a species.

The work described here concerns the effect of drill width and nitrogen level on the seed yield of S37 hay-type cocksfoot, S215 hay-type meadow fescue, and S51 hay-type timothy.

METHODS

Seed of S37, S215 and S51 was sown in drills 36, 24, 15 and 6 in. apart, with two levels of nitrogen equivalent to 52 and 104 lb./acre elemental nitrogen. The treatments for each variety were arranged in an 8 × 8 Latin Square and the sowing rate was based on 5 lb./acre at the 24-in. spacing for S37 and S215 and on 4 lb./acre at the same row width for S51 timothy. The calculated seed rates (lb./acre) for the various drill widths were as follows:

	Drill spacing (in.)				*Seeds per linear inch of drill*
Variety	36	24	15	6	
Cocksfoot S37	3·3	5·0	8·0	20·0	9
Meadow fescue S215	3·3	5·0	8·0	20·0	4
Timothy S51	2·7	4·0	6·4	16·0	20

These figures emphasize the great variation in seed rate per acre accompanying the change in drill width, and also the variation in the number of seeds of each species sown per linear inch, which in turn reflects the variation in weight of individual seeds.

All plots received dressings of 4 cwt./acre of compound fertilizer (NPK 12 : 12 : 18) in the autumn, plus 3 or 6 cwt./acre of nitro-chalk (15·5% N) in March, for three successive harvest years. Autumn and spring cultivation to control weeds was confined to the 15-, 24- and 36-in. spacings, as the 6-in. drills prevented the establishment of other plants in the inter-drill spaces.

The three varieties were sown in separate blocks, and the results are given separately.

TABLE 1. Seed yields lb./acre of cocksfoot S37

Nitrogen level (lb./acre)	Harvest year First	Second	Third	Mean
52 (1N = 1st level)	309	443	274	342·0
104 (2N = 2nd level)	405	478	292	391·6
L.S.D.		33·14*	44·02**	29·52*
Response to N level	96	35	18	
Drill spacing (in.)				
6	281	349	261	297·0
15	382	503	294	393·0
24	386	503	281	390·0
36	379	488	296	387·6
L.S.D.		46·88*	62·28**	41·90**
Mean	357·0	461·7	283·0	
L.S.D. between year means		31·14**		

*P = 0·05 **P = 0·01

RESULTS

Cocksfoot S37

The analysis of variance of seed yields gave significant variations (P=0·01) for drill widths, nitrogen level and years, with first order interactions for year × spacing and year × nitrogen. The mean yields expressed to the nearest lb./acre are shown in Table 1.

These figures show that over three harvest years there was a significant response to the higher level of N applied in spring. Within each harvest year, however, there was a marked differential response which is confirmed by the interaction of nitrogen × year. The data show a diminishing response to N level from the first to the third harvest year.

Close drill spacing significantly affected the yield of seed. Whereas the three drill widths of 15, 24 and 36 in. produced very similar yields throughout, the 6-in. spacing gave very marked reduction in yield in both first and second harvests and also in the overall yield for three years. The interaction of spacing × year appears to be entirely due to the non-significant reduction in yield by the 6-in. drill spacing in the third harvest year. It may be noted that the 6-in. spaced drills, and to some extent the 15-in. drills, had an advantage over wider row spacings in that they required little or no cultivation for controlling weeds and grass seedlings in the inter-drill spaces.

The influence of harvest year on the seed yields of S37 cocksfoot was also significant, as can be expected under western conditions. The annual yields would naturally be influenced by the climate as well as by the increasing age of the stand. First-harvest-year crops are generally expected to produce more seed than older stands, but in this instance the highest yields were produced in the second year. This was probably a result of good pollination conditions accompanying the low June rainfall of 1·25 in., compared with 2·58 and 2·90 in., respectively, in June of the first and third harvest years.

Meadow fescue S215

The analysis of the data for meadow fescue S215 showed that variations due to main effects of spacing, nitrogen level and harvest year were significant at P=0·01. Contrary to the cocksfoot S37 results, there were no significant spacing × year, or nitrogen × year interactions, although these first order interactions have been included in Table 2 for comparison.

It may be seen from the data that the response to nitrogen is highly significant, and, as in S37 cocksfoot, the superiority of 2N over N diminishes with successive harvests. The data show that 6- and 15-in. drill spacings gave higher yields than the 24- and 36-in. drills in each harvest year, and in the mean for three successive harvests. The variation in mean

TABLE 2. Seed yield (lb./acre) of meadow fescue S215

Nitrogen level (lb./acre)	Harvest year First	 Second	 Third	Mean	L.S.D. between means
52 (1N)	400	444	261	368·3	33·12**
104 (2N)	453	483	289	408·3	
Response to N level	53	39	28		
Drill spacing (in.)					
6	449	540	378	455·7	
15	518	552	328	466·0	66·26**
24	435	463	251	383·0	
36	304	299	143	248·5	
Mean	426·5	463·5	275·0		
L.S.D. between year means		38·25*	51·06**		

yields between years is also significant, the seed yield in the third year being considerably lower than in the first and second years. During the first year, aphid attack influenced the seed crop and although dusted twice with derris powder, the 36-in. drills suffered extensive damage; the 24-in. drills were slightly damaged but there were only traces of greenfly on the other two drill spacings. It would seem that the closely spaced drills did not provide a suitable microclimate for the aphids to thrive. In the absence of aphids in the second and third harvest years the narrow drills were superior to the wider spacings.

Timothy S51

The results obtained with timothy S51 (Table 3) show significant response to nitrogen level, drill spacing and harvest year, with no interactions.

The increased yields as a result of doubling the level of N application were very consistent at 17·3%, 19·2% and 15·3% for the first, second and third harvest years, respectively. The 24-in. drills produced a significantly higher yield of seed than the other three spacings, and in turn the 15-in. spacing was superior to the extreme distances. Aphid attack in the first harvest year undoubtedly reduced the seed yield of S51 grown in drills 36-in. apart, but even in the absence of aphids, yields were inferior at this row width in the second and third years.

DISCUSSION

The mean seed yields (Tables 1, 2 and 3) covering three harvest years, show that the three grass varieties in the investigation reacted quite differently to the variation in drill spacings.

TABLE 3. Seed yield (lb./acre) of timothy S51

Nitrogen level (lb./acre)	Harvest year First	 Second	 Third	Mean	L.S.D. between means
52 (1N)	224	146	239	203·0	20·21**
104 (2N)	271	181	282	244·7	
Response to N level	47	35	43		
Drill spacing (in.)					
6	229	158	249	212·0	
15	261	164	272	232·5	20·36*
24	300	178	296	258·0	28·59**
36	200	154	225	193·0	
Mean	247·5	163·5	260·5		
L.S.D. between year means		25·87**			

S37 cocksfoot, which produced very similar yields with 15-, 24- and 36-in. row spacings, showed an appreciable adaptability over this range, but a marked reduction in yield when the rows were 6-in. apart.

Fulkerson (6), working with Oron cocksfoot, states that when considering seed yield, seed quality and ease of weed control, the best combination of treatments was a seed rate of 7½ lb./acre in 14-in. drills for 2–3 seed harvests. In the present investigation the 15-in. drill spacing under the higher fertility level, with an effective seed rate of 8 lb./acre, invariably gave the best yield of seed. In a review of cocksfoot seed production in some European countries, Schwanbom and Froier (12) reported that seed yields of cocksfoot were favoured by drill spacings of 18 to 24 inches. Evers and Sonneveld (4) also found significant reductions in the seed yields of two cocksfoot varieties when grown in 20-cm. (8-in.) drills, but no significant variation was shown between 40-, 50- and 67-cm. spacings.

It is interesting to note that Lindhard and Bagge (10), and Andersen and Poulsen (1) obtained the highest yield of cocksfoot in its first harvest year from broadcast sowing, but during subsequent years the seed yields were higher at wider spacings. This seems to bring forth the nutritional aspect of seed production and is confirmed in some measure by the present data, inasmuch as in the third harvest year the wider drill spacings produced slightly more seed.

With S37 cocksfoot at the lower nitrogen level the highest yields were harvested from the 24-in. drills in the first year, but the 36-in. drill spacing gave higher yields in subsequent harvests. It may be suggested that as the cocksfoot stand gets older there is greater competition for soil nutrients, and in order to maintain the level of the seed produced in the first year, wider drill spacings or more nitrogenous fertilizer are required.

At the higher nitrogen level the best yields and the greatest response to additional nitrogen were produced at the 15-in. spacing in each of the three harvest years. Very similar results are quoted in the Ontario Annual Report (11) where a 14-in. spacing gave higher seed yields of cocksfoot over two harvest years than wider spacing or broadcast sowing. In the third and fourth harvest years it was found that 28- and 35-in. drill spacings were superior to 14-in. drills or broadcast sowing.

The S215 meadow fescue gave significantly better yields when sown at the narrow spacings of 6 and 15 inches. The latter appears to be slightly better under both fertility levels, and also in its response to the higher N level. These data confirm Danish results (10) with meadow fescue, which show that the best yields were produced by the 40-cm. (16-in.) spacing. Many workers (8, 10, 14) agree that meadow fescue should be sown in drills, but opinions differ as to the optimum spacing. It should be borne in mind, however, that cultivation is not practicable with less than 30 cm. (12 in.) between the drills.

These varying results could be affected to some degree by the variety used in the investigations. Evers and Sonneveld (4) found that the seed yield of a pasture type of meadow fescue sown in drills 25 cm. apart was superior to that produced at wider spacings (33, 40, 50 and 67 cm.). The seed rate per unit length of drill used by these workers was similar for all drill widths and was based on 6 kg./ha. (6 lb./acre) at the 50-cm. (20-in.) spacing. The effective seed rate per acre at the 25-cm. width would thus be approximately 12 lb./acre, compared with 8 lb. of the S215 seed at the optimum spacing of 15 in. (50 cm.). The above evidence strongly suggests that meadow fescue is not capable of utilizing wide drill space as advantageously as cocksfoot or timothy.

In order to investigate the matter further, trenches were dug across the 36-in. drills following the harvest in the third year, and it was observed that the horizontal and vertical spread of the roots of the fescue was less than that of the cocksfoot. The aerial growth of the meadow fescue lacked vigour after three seed crops, and the relatively confined root growth might be indicative of poor vegetative growth rather than of low capacity of the meadow fescue to utilize such wide inter-drill spaces. The cocksfoot drills, exhibiting strong vegetative growth, showed a 30–36-in. horizontal and a 9–12-in. vertical spread of roots.

The results obtained with meadow fescue indicate the same reaction to drill spacing as with perennial ryegrass, where broadcast sowings produced higher seed yields than the drill crops (9), especially in the first harvest year (2, 5). In Germany (14) and Finland (13) close drills (20–45 cm.) have repeatedly given the best results.

From the practical standpoint, the growing of meadow fescue for seed in closely-spaced drills, or broadcast, seems to have many advantages over growing in wide drills.

An extremely important consideration when growing meadow fescue is the prevention of seed shattering in lodged crops. When this grass is sown in drills 24 in. apart (± 6 in.) the seed heads fall between the drills and at harvest lie below the level of the knife. Even if a satisfactory cut can be made, a considerable loss of good seed occurs in lifting the swath before threshing. Close drills successfully overcome this difficulty.

Timothy S51 proved the most uniform species in its reaction to drill spacing and nitrogen application. At both fertility levels the 24-in. spacing gave the best yield of seed in each harvest year and the mean yield over three years was higher by 17%, 10% and 25% than those obtained from the 6-, 15- and 36-in. spacings. The highest response to doubling the application of N was also exhibited in each harvest year by this drill spacing. The results obtained by Evers and Sonneveld (4) with Barenza hay-type timothy similarly showed that crops sown in 67-cm. drills gave superior seed yields to those sown at 40- and 50-cm. spacings. These workers also found that a grazing type of Barenza timothy preferred a slightly closer drill spacing of 50 cm. when sown at 3 kg./ha. In another investigation over 4 harvest years (3) a drill spacing of 60 cm. proved to be markedly superior to one of 25 cm. Similar results were found by Hagsand (7) and although the 45-cm. drill spacing proved optimal, the wider spacings gave significantly higher responses to nitrogen.

Seed crops of Aberystwyth herbage varieties are grown under contract for a period normally covering two successive harvest years, they rarely extend beyond the third seed crop. The present results over a similar period show that species differ widely in their reaction to drill spacing. It is nevertheless remarkable how closely these findings agree with the results obtained by workers in other countries. The difference between varieties cannot therefore be expected to be very significant, although Evers and Sonneveld have shown that a grazing type of perennial ryegrass (5) and a grazing variety of timothy (4), as previously mentioned, prefer slightly narrower drill spacings than their hay counterparts.

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THE ESTIMATION OF 'GREEN DRY MATTER' IN A HERBAGE SAMPLE BY METHANOL-SOLUBLE PIGMENTS

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To estimate the proportion of the total dry matter of a herbage sample which arises either from dead or from green herbage, four methods have been compared. One of the methods, the pigmentation method, is described.

INTRODUCTION

A sample of a hill sward always contains a large amount of dead herbage, and it is necessary to estimate the proportion of the total dry-matter yield derived from green herbage. Most hill grasses are fine-leaved and hand separation of a sub-sample into dead and green herbage is tedious and slow; alternative methods have therefore been studied.

METHODS

The samples—in this study, 12 per area of plant community—are cut, weighed immediately to find their fresh weight, placed in rubber bags and returned to the laboratory. They may be from caged enclosures or from areas open to grazing and, while they are being cut, two further samples per area are collected, one of dead and one of green fresh grass. The dead sample is not taken at random but is gathered from the tussocks where it is easiest to collect a large amount. There is little variation among samples of dead grass, and this procedure so reduces the time needed to collect a sample that it appears justified. The green sample is collected from within the areas cut for the fresh yield estimation: any green or dead material is removed to give a pure sample.

In the laboratory the yield samples are thoroughly mixed and sub-samples of 200 or 300 g. are dried in the oven to estimate D.M.%. The dead and green samples are also weighed and dried to determine their D.M.%; the C.P.% of the dead, green and yield samples is estimated. A further sub-sample from each of the yield samples is placed in a scrim bag and air-dried.

The percentage of the total dry matter of the yield samples which is derived from green grass is then estimated in the following ways:

(1) by hand separation of the air-dried sub-samples;

(2) by calculation, using the data on either the crude protein or dry matter of the dead, green and yield samples (the method for doing this has been described (1));

(3) by the pigmentation method.

Pigmentation method

The oven-dried dead and green samples are ground in an 8-in. Christy-Norris mill fitted with a 2·45 mm. sieve, and 2 g. mixes of the dead and green ground material are weighed into beakers to cover the range 100% dead to 100% green at 10% intervals. Twenty ml. of methanol are then added to each mix and the mixes shaken intermittently for 20 minutes. The methanol extracts the pigments from the ground grass and the extract is filtered off. The colour density of the filtrates is then measured on an EEL absorptiometer, using a 2·5 ml. cell and setting the 100% 'dead' extract at 100% light transmission; Filter No. 608 is generally found to be the most suitable. A calibration graph is then made by plotting the percentage green in the mix against the percentage light absorption. With the material used, this procedure has given a sensitive and almost linear calibration graph.

Two-gram portions of the yield samples, oven-dried and ground, are extracted in the same manner as was the material used to prepare the calibration graph. The percentage light absorption of their extracts is found on the absorptiometer, and reference to the calibration graph gives their G.D.M.%. The setting of the absorptiometer to determine the calibration graph must remain unaltered for measuring the absorption given by the 'unknowns'. It is necessary to make a calibration graph for each group of samples having a common date of cutting, origin and treatment.

The sources of error in this method are as follows:

(1) The methanol extract of a small sample (50 g.) has a less dense pigmentation than that of a large sample (200 g.) where both samples are of identical material and have each received similar treatment prior to extraction. This difference is a mill effect. It is thought that the mill grinds a small sample less finely than a large one and that the rate of extraction of the pigments is related to particle size. This cause of error could be avoided if the large sample was split into portions of the same size as the small sample and each portion cleared through the mill before beginning to grind the next.

(2) The pigments are sensitive to heat and light. It is therefore necessary to: (a) test the drying oven for uniformity; (b) store all samples away from the light; (c) ensure that all the samples in a group receive identical treatment in respect of periods and temperature of drying.

(3) Species differ in their degree of pigmentation (Table 1). The occurrence of varying proportions of different species in the yield samples will add to the sampling error; in a more botanically homogeneous sward this would be reduced.

TABLE 1. Comparative pigmentation of species

Percentage light absorption of methanol extract of 2 g. D.M. sample. Absorptiometer set to give 100% light transmission through methanol. Filter No. 603. Samples collected July 1959.

	Species					
	Festuca ovina	*Holcus mollis*	*Achillea millefolium*	*Nardus stricta*	*Deschampsia flexuosa*	*Deschampsia caespitosa*
% Absorption	50	55	78	52	68	78

TABLE 2. Coefficient of variation and mean D.M. and G.D.M. (g.) of 12 yield samples

Sample area 1·5 sq. yds. (To find lb./acre/D.M. or G.D.M. multiply by 7·1). Samples cut August 1959.

Source of samples			Caged sward below bracken canopy		*Agrostis-fescue* sward				Significant difference $P<0{\cdot}05$
					Site 1		Site 2		
			Site 1	Site 2	Caged	Uncaged	Caged	Uncaged	
Total D.M. before separation		Mean yield	62	171	236	206	227	170	
		C. of V.	41	39	22	22	30	28	
Green D.M. yield:									
Separation method	D.M. %	Mean yield	58	90	176	135	181	110	31
		C. of V.	45	38	22	15	33	30	
	Pigmentation	Mean yield	48	88	176	129	161	127	
		Corrected mean yield	48	90	157	124	147	96	30
		C. of V.	45	35	26	20	31	30	
	Hand separation	Mean yield	49	94	167	123	147	98	26
		C. of V.	37	37	23	18	27	24	
	Crude protein %	Mean yield	—	—	128	104	152	116	NS
		C. of V.	—	—	33	24	39	32	
	Cut No.		1	2	3	4	5	6	

COMPARISON OF METHODS

The G.D.M. yield was estimated by the four methods in 6 cuts, each composed of 12 samples taken from hill pastures in the summer of 1959 (Table 2).

(a) *Coefficients of variations* (*Table 2*)

Of the four methods, hand separation gave the G.D.M. estimate with the lowest C.V. and one which was less than that of the total D.M. of the yield samples. This does not necessarily mean that it is a better method, as this reduction may be due to the method recognizing only two classes, dead and green, and ignoring the variance in pigmentation, C.P.% and D.M.%, which exists within these two classes.

(b) *Labour and time requirements*

If time taken in calculation is excluded, then the D.M.% method has no labour requirements; the pigmentation method is six times faster than the hand separation of 10 g. air-dried samples when samples are in groups of 12, and its relative speed will increase as the number of samples in a group increases.

(c) *Ranking of G.D.M. yields according to method of estimation*

The 6 cuts give 15 pairs for comparison of differences among G.D.M. mean yields as found by the different methods. (The C.P.% method indicated no significant differences among the mean G.D.M. yields and is not considered further under this heading.) The members of 13 of these pairs were ranked in a similar manner where $P<0{\cdot}05$. Of the remaining 2 pairs, the pigmentation and D.M.% methods agree, except for the comparison of cut 6 with cut 2, while the hand separation method differs in both pairs from the pigmentation method (cuts 5 and 4, 6 and 2) and from the D.M.% method for pair 5 and 4.

The discrepancy between the pigmentation and the hand separation method is due to the mill effect. The discrepancy between the D.M.% and the hand separation method is due to the D.M.% method over-estimating the G.D.M. yield of cut No. 5, because the samples were very slightly damp with dew when cut.

DISCUSSION

Among the methods the D.M.% is the fastest. Its application, however, is severely restricted under hill pasture conditions in Great Britain as our grass is seldom free from adhering moisture.

We have not had sufficient experience of the C.P.% method to recommend that it should replace hand separation. It is, however, likely to be less efficient than the D.M.% method, as the difference between dead and green herbage in their C.P.% (approximately 7% C.P. in dead, 12% in green) is much less than in their D.M.% (approximately 90% D.M. in dead, 30% in green) and the wider the ratio between dead and green in the constituent employed in the calculation the less important the sampling error will be. (It is notable that the C.V. of the estimate by the C.P.% method is higher than by any other method.)

We are of the opinion that the pigmentation method is an adequate substitute for the hand separation method, provided that there is no great variance in species composition among the yield samples. The correlation between the hand separation and pigmentation methods is sufficiently high to correct an over- or under-estimation due to the pigmentation method, by hand separating 3 out of each set of 12 samples, subsequently correcting all the pigmentation estimates by the average discrepancy between the three hand separation and allied pigmentation estimates. This was done on the data used in this paper. (Table 2 pigmentation method corrected mean yield row.)

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SOME ECONOMIC ASPECTS OF THE APPLICATION OF PHOSPHATES TO PERMANENT PASTURES IN IRELAND

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During the years 1957 to 1959 a number of trials carried out at various centres throughout the country showed that the yield of Irish pastures could be greatly increased through the application of fertilizers. Phosphorus increased both yield and the protein content of herbage. The increase in yield was a linear function of the initial P status of the herbage. For the series as a whole, phosphorus increased the yield by approximately 20%, potassium by 7% and phosphorus and nitrogen by 45%. The national and sociological implications of these results are discussed.

INTRODUCTION

It has been estimated (2) that the mean yield from Irish pastures is approximately 14 cwt. of Starch Equivalent per acre. This may be crudely interpreted as signifying that, on the average, it requires 2·6 acres to produce the food requirements of a cow giving 600 gal. of milk annually. In areas with a climate not materially different, it has been found (6, 9) that such a cow can be carried on an area of from 0·8 to 1·5 acres.

A number of studies have been made regarding the causes of this low production from Irish pastures (2, 12, 15), and the general conclusion has been that yield is limited mainly through lack of fertilizers and lime.

Although the value of fertilizers for grassland has been amply demonstrated at Experimental Stations in this country, there is an impression that the results obtained are not necessarily applicable on other soil types or under conditions of less efficient grazing management. Consequently some trials of a simpler nature, in which the effect of fertilizers in increasing the output of a pasture could be demonstrated on a local basis, were needed.

MATERIALS AND METHODS (GENERAL)

The trials were carried out on commercial farms throughout the country during the years 1957 to 1959, inclusive. The sites were selected by the local agricultural advisory officers as typical of the grassland in the area. The area under each treatment was usually one acre and this was subjected to continuous grazing throughout the experiment.

Yields were determined by taking clippings from areas 11 × 5 ft. which had been protected from grazing by means of wire cages. The grass was harvested 3 or more times in the course of the grazing season, and samples were analysed. Except in the final year, cages were put back on the same area after each harvesting: although this procedure is open to some objections, it obviated pre-trimming another area by hand. It also protected the area from poaching, which was an important consideration in some localities. Harvesting was carried out by the advisory officers, to whom the authors are indebted.

FIRST-YEAR EXPERIMENTS

The experiment was carried out at ten centres, and there were two treatments: (a) old pasture unfertilized, and (b) old pasture + phosphate. The rate of application of this fertilizer ranged from 2 to 4 cwt. per acre, depending on the initial phosphate status of the soil. The results are shown in Fig. 1. It will be seen that the size of the response varied considerably from one centre to another, and although the smallest responses were obtained where the yield was already high, the converse did not always obtain.

It seemed probable, therefore, that poor response to fertilizer was due not to an

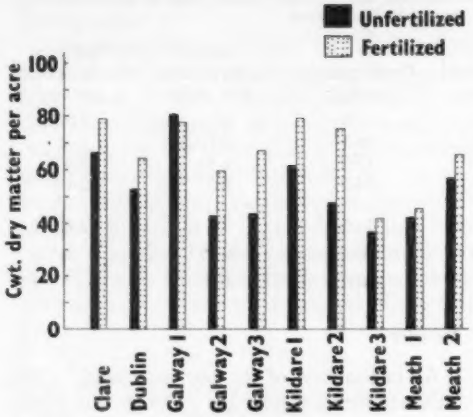

Fig. 1. Effect of fertilizer in increasing the yield of dry matter of permanent pasture.

initially high phosphorus status in the pasture but to the occurrence of some other limiting factor. Since both the clover content and the organic-matter status of many Irish pastures are low, it seemed probable that nitrogen was the limiting factor. In all subsequent trials, therefore, nitrogen was included as a treatment.

SECOND-YEAR EXPERIMENTS

As in the previous year, the new sites were selected and the cuttings taken by the local agricultural advisers.

Treatments were as follows: (1) control; (2) superphosphate 4 cwt./acre; (3) muriate of potash 1½ cwt./acre; (4) superphosphate 4 cwt. + muriate of potash 1½ cwt./acre; (5) superphosphate 4 cwt. + muriate of potash 1½ cwt./acre + sulphate of ammonia, 1 cwt./acre.

All fertilizers were applied in the spring, and chemical analyses were carried out by routine methods (25).

Results

A summary of the results is shown in Table 1; the detailed results for individual centres will be published elsewhere. Since the production of grass is not an end in itself, an attempt was made to express the results not only in terms of dry matter, but also, however crudely, in units of animal production. This was done by dividing the annual food requirements of a cow (in lb. of dry matter) by the yield obtained. To do this it was necessary to make two broad assumptions: first, that a cow consumes 33 lb. of dry matter daily (26), and second, that the same yield of dry matter would be obtained from hay as from grazing. An example will illustrate how the calculation was made: if a treatment gave a yield of 50 cwt. dry matter per acre, then the number of acres required per cow was taken as $\frac{33 \times 365}{112 \times 50} = 2{\cdot}15$

It is well known, however, that only a fraction of the herbage grown is utilized. Recent work in New Zealand (11) has shown that, even with a stocking rate of one cow per acre 'there is an estimated invisible wastage amounting to 35% of the herbage actually available'. The losses of dry matter in haymaking in Ireland have been shown to be of the order of 25–33% (19). The figures given in the last column of Tables 1 and 2 represent the area on which, in theory, the food requirements of a cow can be grown: in fact, the area required to carry a cow would be at least one and a half times as large.

Discussion of Table 1

It will be seen that the application of phosphate practically always resulted in a substantial increase in the yield of dry matter. For the series as a whole, the increase was approximately 20%. In some areas there was also a substantial response to potassium. Over the entire experiment, however, potash caused an increase of 7% over the control. The most outstanding feature of the results is the spectacular response to the very small application of nitrogen. For the series, this increase amounted to approximately 15% over that obtained by a combined dressing of phosphorus and potassium.

The use of dry matter as a measure of the output of pastures is open to many criticisms, the chief of which is that the highest yields may be associated with herbage of inferior feeding value. It will be observed that in the foregoing

TABLE 1. **Effect of phosphorus, potassium and nitrogen on the yield and chemical composition of pastures (1958)**
Results are the mean of 21 centres in 18 counties

Treatment	Yield of D.M. cwt./acre	Mean % P in D.M.	P recovered lb./acre	Crude protein mean %	Yield of crude protein cwt./acre	Estimated acres of land per cow
Control	44·8	0·27	13·9	13·5	6·1	2·61
Superphosphate	53·0	0·40	23·7	14·3	7·7	2·15
Muriate of potash	49·0	0·28	15·6	13·8	6·9	2·47
Phosphate + potash	56·0	0·40	25·4	14·5	8·3	2·17
Phosphate + potash + nitrogen	65·1	0·39	29·2	14·3	9·5	1·84
S.D. for P=0·05	**4·4**	**0·04**	**2·9**	**0·6**	**0·77**	
S.D. for P=0·01	*5·9*	*0·05*	*3·8*	*0·8*	*1·0*	

experiment, the application of fertilizers increased both the phosphorus and the crude-protein content of the herbage. In view of the fact that aphosphorosis was, and possibly still is, fairly widespread in Ireland (20, 23), this is a matter of importance. The use of dry matter as an index of yield in this instance has therefore the effect of under-estimating the value of the improvement brought about by fertilization.

THIRD-YEAR EXPERIMENTS

During the year 1959 a further series of experiments was undertaken at twenty-four new centres. The general procedure was as in previous years and treatments were as follows: (1) control; (2) superphosphate 3 cwt./acre; (3) superphosphate 3 cwt./acre + sulphate of ammonia 1 cwt./acre; (4) superphosphate 6 cwt./acre + sulphate of ammonia 1 cwt./acre.

Results

As in the case of the previous years' trials, only the mean results are given in this paper. These are set out in Table 2.

Discussion of Table 2

The findings are in general very similar to those of the previous year, and the increase due to superphosphate was 15–20%. For the experiment as a whole there was little difference between 3 and 6 cwt. of superphosphate per acre, which indicates that the lower dressing was near the optimum. In a similar series of trials carried out with root crops, the mean response to phosphate was in the region of 40–50% (24). It would seem, therefore, that under pasture conditions the potential response is limited by other factors, of which nitrogen deficiency seems to be the most important. It is well known that the application of phosphates will often increase the clover content of

TABLE 2. **Effects of phosphate and nitrogen on the yield and chemical composition of pastures (1959)**
Results are the mean of 22 centres in 19 counties

Treatment	Yield of D.M. cwt./acre	Mean % P in herbage	P recovered lb./acre	Crude protein mean %	Yield of crude protein cwt./acre	Estimated acres of land per cow
Control	46·6	0·25	13·2	15·1	7·1	2·44
Superphosphate @ 3 cwt./acre	54·0	0·32	19·5	16·0	8·7	2·07
Superphosphate @ 3 cwt. + nitrogen	58·7	0·32	21·3	15·7	9·5	1·88
Superphosphate @ 6 cwt./acre + nitrogen	62·6	0·37	25·1	16·4	10·1	1·72
S.D. for P=0·05	**3·7**	**0·02**	**2·0**	**0·74**	**0·74**	
S.D. for P=0·01	*4·9*	*0·03*	*2·7*	*0·98*	*0·98*	

pastures and this in turn results in an improved nitrogen status.

The response to phosphorus is therefore twofold; direct, through supplying the element itself, and indirect, through increasing the clover and ultimately the nitrogen content of the sward. In the absence of a basal dressing of nitrogen, therefore, the yield response will be governed to some extent by the capacity of the sward to increase in clover content. This increase in clover is by no means automatic, as will be seen from the results of some botanical analyses carried out at the end of the first year.

TABLE 3. Botanical composition at the end of the first season's grazing

Grasses and weeds are quoted as plant units per foot (8) and legumes as inches of creeping stem

		Grass	Clover	Weeds
Carlow	Control	545	140	9
	P_3	926	280	21
Dublin (a)	Control	485	330	31
	P_3	319	278	24
Dublin (b)	Control	646	178	64
	P_3	588	509	39
Kildare	Control	536	88	98
	P_3	414	468	142
Kilkenny	Control	961	150	55
	P_3	854	134	78
Offaly	Control	699	189	62
	P_3	679	167	36
Wicklow	Control	920	298	16
	P_3	633	240	27

P_3=Superphosphate, 3 cwt./acre

It will be seen that where the clover content was already high, as in Dublin (a) and Wicklow, there was no change in botanical composition. At some centres there was a striking increase in clover content, while at two locations, Kilkenny and Offaly, even though clover was not abundant initially, there was no increase in this species following phosphate application. Such an effect has previously been recorded by Murphy (14) who found that the maximum development of clovers did not occur until the third year after fertilization. As in the previous year, superphosphate increased both the phosphorus and crude-protein content of the herbage.

GENERAL DISCUSSION

It will be noted that the yields from the untreated pasture were very similar for the years 1958 and 1959. On the basis of Watson's regression equation (26), the mean yield for the two years (45·5 cwt. per acre D.M. with a mean crude-protein content of 14·3%) would be 26·25 cwt. of starch equivalent. Allowing that approximately 65% of this would be consumed (11), the utilized output would then be 17·0 cwt. S.E. per acre, which is not very different from the estimated average output of Irish pastures (2, 15). Consequently, it was felt that these figures would form a reliable basis on which to make some studies on the economics of phosphatic fertilizers for grassland in the Republic of Ireland.

THE ECONOMICS OF PASTURE FERTILIZATION

Although the more widespread use of fertilizers is desirable from a national point of view, the individual farmer is more concerned about its profitability on his own farm. Two main uncertainties confront the farmer: (i) what is the probability of his getting a response to fertilizers on his farm? (ii) by how much will his production be increased?

(i) *The probability of a response to phosphate on individual farms*

There is abundant evidence (20, 21, 22, 23) that most Irish pastureland is deficient in the essential nutrients. The chances of a soil not being deficient in at least one element are more than three to one. The intelligent use of soil and herbage analysis can eliminate still further the possibility of wasting money on unnecessary fertilizer. In this connection, however, it should be borne in mind that the results of soil tests must be interpreted on a regional basis, for there is evidence that individual soil types differ markedly in their capacity to release phosphorus to the solutions normally used in soil analysis (13). For this reason herbage analysis has been preferred to soil analysis in these investigations.

The relationship between yield increase and the phosphorus content of the herbage is shown by means of a scatter diagram (Fig. 2).

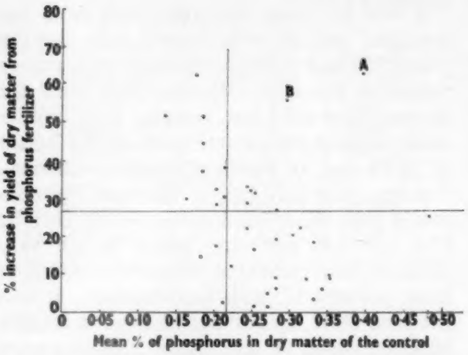

Fig. 2. Scatter diagram showing the relationship between increase in yield of dry matter and phosphorus content of the unfertilized herbage.

This gave a correlation coefficient of $-0{\cdot}390$ which is significant at the 5% level. If points A and B are eliminated, the figure becomes $-0{\cdot}680$ which is significant at the 1% level. It seems probable that, in these two instances, the response was to the sulphur and not to the phosphorus in superphosphate.

Provided that multiple deficiencies do not exist, therefore, the chances are very much in favour of the individual farmer obtaining a substantial increase in yield from the application of superphosphate.

(ii) *Expected increase in yield of dry matter from the use of fertilizer*

To date few data connecting the yield of herbage with the rate of fertilizer application are available. Although the foregoing results concern forty-five centres only, they provide a general indication of the size of the response to be expected from the use of phosphatic fertilizer.

A regression equation calculated by the method of least squares (10) gave the following results: $Y=70{\cdot}34-138{\cdot}6x$, where $Y=\%$ increase in yield due to superphosphate, and $x=$the content of phosphorus in the original herbage. The results, together with the 5% and 1% confidence limits, are shown in Fig. 3.

This shows that at very low levels of phosphorus in the herbage, an increase in yield of the order of 30–50% might be expected. On the other hand, where the phosphorus content of the herbage is in the region of 0·35% to 0·40% the increase will usually be less than 15%.

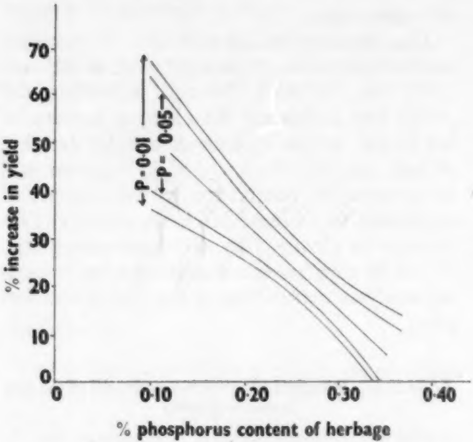

Fig. 3. Regression line and confidence limits for relationship between increase in yield and phosphorus content of the original herbage.

The scope of the experiments did not permit the making of similar predictions regarding the effects of potassium and nitrogen, but from the results in Tables 1 and 2, it will be seen that the effect of phosphorus depended upon the levels of potassium and of nitrogen, particularly the latter.

Financial returns from fertilizers

Apart from that contained in the work of Imperial Chemical Industries, there is little information on the economic returns from fertilizers applied to grassland. This is because it is exceedingly difficult to obtain reliable figures for the output of animal enterprises and, having obtained such data, it is difficult to partition the output between labour, capital and other resources.

O'Connor (16) has in a recent study calculated the gross output per acre of pasture utilized by different categories of animals. When any subsidies are allowed for, his results for Ireland are in general agreement with those obtained in Britain (4). Under

TABLE 4. Estimated financial returns from the use of fertilizers on grassland

Fertilizer prices are in respect of the period Feb. to May 1959 (7)

Column	Item	Dairying*	Dry Cattle**	Sheep†
I	Gross income/acre according to O'Connor's data (16)	£29·6	£19·9	£25·7
II	Feed as % of the cost of production (4)	60%	78%	69%‡
III	Estimated value of gross per acre without fertilizer (I×II)	£17·8	£15·5	£17·5
IV	Average increase in yield of DM following application of phosphate	18·18%	18·18%	18·18%
V	Estimated value of increase in yield from P (III×IV), minus cost of fertilizer	£1·49	£1·07	£1·43
VI	Average increase in yield following application of N+P+K	45·3%	45·3%	45·3%
VII	Estimated value of increase in yield from N+P+K (III×VI) less cost of fertilizer	£4·46	£3·42	£4·33

*Assuming a cow gives 500 gal. milk, sold at 15d. per gal.

**Fattened off grass at 26 months old.

†Fat lamb production from lowland sheep.

‡Table D 2. ref. (4).

British conditions, food costs represent approximately 60% of the total cost of milk production. In the National Farm Survey (3) 1955–6, labour and family income equalled approximately 60% of the gross income. Taken from either of two points of view, therefore, approximately 60% of the increased income from fertilizers could be regarded as 'profit'. Assuming (i) that animals could be fed entirely on grass as pasture, hay and silage, and (ii) that the cost of food maintains a constant ratio to gross output over a wide range of pasture-production levels, increased returns from fertilizers could be estimated as shown in Table 4.

Discussion of Table 4

Although the final figure obtained is not, strictly, net increase, it is very nearly so under the conditions prevailing in Ireland. Apart from this, the treatment of the data has been rigorous and the results are therefore to be regarded as conservative estimates of the value of fertilization: e.g., the response to phosphorus has been taken as 18%, although, as may be seen from Fig. 3, it may increase the yield by as much as 50%, depending on its initial status in the herbage.

It should be borne in mind that the gross output per acre of the majority of Irish farms (3, 16) is in the region of £14 per acre, of which about £8 is net output. Hence an increase of £1 to £3 net represents a substantial addition to the existing family farm income.

Furthermore, although the cost of the fertilizer has been more than recovered in the year of application, the effect on yield is not limited to one year. This is well illustrated (Fig. 4) by some data from a long-term trial at Johnstown Castle (1). Moreover, such responses to phosphatic fertilizers are not obtained at the expense of deterioration of the sward, as frequently occurs with the use of high levels of artificial nitrogen. On the contrary, all available data indicate that with the

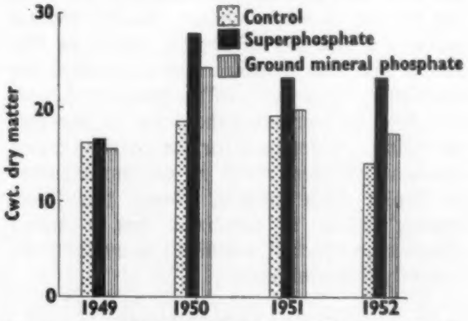

Fig. 4. Effect of superphosphate and ground mineral phosphate on the yield of pasture over a 4-year period: both fertilizers applied at 4 cwt. per acre in 1949.

application of phosphate or potassium the botanical composition of old swards may be markedly improved (1, 18). Consequently, the increase in yield from fertilization is capable of being maintained and possibly further increased in subsequent years.

It should also be borne in mind that the system of management employed in this experiment resulted in the complete removal of nutrients from the pasture. Under normal grazing conditions there would be a return of dung and urine, which would result not only in further increases in yield, but also in ecological changes in the flora and in increased earthworm activity in the pasture.

SOCIAL AND NATIONAL CONSIDERATIONS

It has been estimated that some 25% of the volume of the food produced in the U.S.A. during the Second World War could be attributed to the use of fertilizers alone (17). The foregoing results show that with the application of moderate quantities of fertilizer, the stock-carrying capacity of Irish pastures can be increased by 20%–50%.

A substantial part of this increase would arise through the greater thriftiness and better quality of livestock, due to the improved feeding value of the herbage (21). The main increase, however, would come from the increased stock-carrying capacity of the pasture. In Ireland many holdings are described as uneconomically small (5). On most of these uneconomic holdings there is a surplus of family labour; hence income becomes a function of capital, which in this case is land and livestock. Any increase in the stock-carrying capacity of the pastures should, therefore, by increasing the gross income and providing a wider base for the distribution of overhead charges, result in an improvement in family farm income. Hence this 'land sparing' effect of fertilizers has a social significance which it is difficult to evaluate on a strictly financial basis.

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STUDIES OF THE GROWTH OF A *HYPARRHENIA*-DOMINANT GRASSLAND IN NORTHERN RHODESIA

II. FERTILIZER RESPONSES

III. THE EFFECT OF FIRE

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INTRODUCTION

When describing the results of fertilizer experiments, Pawson (3) commented on "the almost complete dearth of scientific information on the fertility status of Northern Rhodesian soils". In his studies on maize this worker demonstrated that nitrogen was the prime limiting factor on the soils he studied but that responses to phosphate application could be obtained on certain types, particularly those with a light texture.

The substantial increases in yields of maize grain and stover, which Pawson obtained from the application of fertilizers, suggested that the yield of herbage from grassland might also be limited by the supply of plant nutrients. A systematic investigation of fertilizer responses in both natural grasslands and cultivated pastures by means of field experiments was accordingly initiated. The results of the trials described below relate only to *Hyparrhenia*-dominant grassland on the reddish-brown clays of the Mount Makulu Central Agricultural Research Station. Experiments concerned with other soil and grassland types will be reported later.

EXPERIMENTAL

A 2^4 factorial design with partial confounding of the third order interaction was used in the first fertilizer experiment on this *Hyparrhenia*-dominant grassland. The 32 plots were arranged in 4 blocks of 8 units. Overall plot size was 6×6 yds. (1/134th acre) and effective plot size 5×5 yds. (1/194th acre).

The fertilizer treatments were as follows:

N—sulphate of ammonia (21% N) @ 0 & 400 lb. per acre.

P—superphosphate (19% P_2O_5) @ 0 & 300 lb. per acre.

K—muriate of potash (60% K_2O) @ 0 & 100 lb. per acre.

L—agricultural lime @ 0 & 1000 lb. per acre.

The sulphate of ammonia was split into two equal dressings of 200 lb. per acre, the first applied with the onset of the rains and the second immediately after the first cut. All the other fertilizers were applied as a single dressing at the beginning of the wet season. The fertilizer dressings were repeated in the second and third years of the experiment but were omitted in the fourth to assess residual effects. The herbage was cut twice per season, at the early flowering stage, and weighed fresh in the field. Facilities for dry-matter determination and chemical analysis were not available in the first year, but in the second and subsequent years herbage samples were taken for these purposes.

Fertilizer responses are presented in Tables 8, 9 and 10.

The most striking feature of the results was the consistent and highly significant increases in yield of herbage and crude protein which resulted from application of sulphate of ammonia. Increases in yield with the addition of superphosphate were small compared with the responses to sulphate of ammonia and did not always attain significance, but there was an indication that this fertilizer might be important if sustained high yields were to be achieved. On the other hand the small apparent increases in yield with dressings of muriate of potash were not significant, even at the 10% level, and lime appeared to have a depressant effect, although this was rarely so large as to be significant.

TABLE 8. N.P.K. and lime fertilizer trial on *Hyparrhenia* grassland (lb. per acre of herbage)

Season	N	P	K	L	Significant effect at 5% level	General mean
1955–6 Fresh weight	*+6651*	+651	+830	−209	1206	14,257
1956–7 Fresh weight	*+6381*	*+2275*	+691	−1026	1049	12,836
Dry weight	*+1979*	*+609*	+71	*−442*	355	3,992
1957–8 Dry weight	*+898*	*+266*	+79	−273	279	3,039
1958–9 Dry weight*	*+303*	*+282*	−9	−104	245	2,935

Positive effects indicated by a plus sign, negative effects by a minus sign.
Effects significant at 5% level shown in italics.
*Residual effects, no fertilizer applied.

TABLE 9. Fertilizer trial on *Hyparrhenia* grassland. Yields of crude protein (lb. per acre)

Season	N	P	K	L	Significant effect at 5% level	General mean
1956–7	*+103·2*	+21·1	−1·6	−44·4	50·6	158·7
1957–8	*+87·8*	*+26·7*	+11·9	*−28·3*	22·2	220·7
1958–9*	+14·8	*+20·3*	+2·2	−10·2	15·8	151·0

Positive effects indicated by a plus sign, negative effects by a minus sign.
Effects significant at 5% level shown in italics.
*Residual effects, no fertilizer applied.

TABLE 10. Fertilizer trial on *Hyparrhenia* grassland. Crude-protein content of herbage expressed as percentage of dry matter

Season		N	P	K	L	Significant effect at 5% level	General mean
1956–7	1st cut	+0·19	+0·11	−0·07	−0·19	0·39	2·52
	2nd cut	+1·04	−0·26	−0·12	−0·76	1·40	6·11
1957–8	1st cut	*+0·56*	+0·21	*+0·41*	−0·09	0·38	7·81
	2nd cut	*+0·82*	+0·23	+0·08	*−0·32*	0·25	6·74
1958–9*	1st cut	0·10	+0·20	+0·01	+0·04	0·40	5·35
	2nd cut	−0·15	+0·14	+0·11	*−0·33*	0·28	5·04

Positive effects indicated by a plus sign, negative effects by a minus sign.
Effects significant at 5% level shown in italics.
*Residual effects, no fertilizer applied.

The changes in percentage crude protein which were induced by the fertilizer dressings in this experiment were small, but there was some indication that sulphate of ammonia increased it.

Significant residual effects of both sulphate of ammonia and superphosphate were recorded in the fourth year when no fertilizers were applied.

In view of the responses to sulphate of ammonia which were obtained in the first experiment, it was decided to investigate the responses to a number of levels of this fertilizer, both alone and in combination with superphosphate and muriate of potash, in a second trial. A 4×2^2 factorial design, with partial confounding of the second order interaction, was used for this purpose. The 48 plots were arranged in 6 blocks. Overall plot size was 1/538th acre. These small plots were employed as experience in other trials indicated that the reduction in size, compared with those of the first experiment, should lead to little, if any, loss in accuracy.

Fertilizer treatments in the first season (1957–8) were:

N_0—0 lb. sulphate of ammonia per acre.
N_1—400 lb. ,, ,, ,, ,, ,,
N_2—800 lb. ,, ,, ,, ,, ,,
N_3—1200 lb. ,, ,, ,, ,, ,,
P_0—0 lb. superphosphate per acre.
P_1—400 lb. ,, ,, ,,
K_0—0 lb. muriate of potash per acre.
K_1—200 lb. ,, ,, ,, ,, ,,

All the fertilizers were applied at the beginning of the wet season in one dressing. The herbage was cut twice during the season at the early flowering stage. The results in the

TABLE 11. N.P.K. fertilizer trial on *Hyparrhenia* grassland: yields of dry matter as pounds per acre in 1957-8 season*

	N_0	N_1	N_2	N_3		P_0	P_1
K_0	2176	3650	4062	4119	3502	3222	3782
K_1	2140	3904	4086	3993	3530	3053	4008
	2158	3777	4074	4056	3516	3137	3895
P_0	2251	3224	3519	3558	3138		
P_1	2066	4330	4629	4555	3895		

Least significant differences between two means at 5% level:

N.K. and N.P. tables	1068
P.K. table and mean N	755
Other means	533

TABLE 12. N.P.K. fertilizer trial on *Hyparrhenia* grassland: yields of crude-protein as pounds per acre in 1957-8 season*

	N_0	N_1	N_2	N_3		P_0	P_1
K_0	168·8	333·3	418·7	493·9	353·6	319·0	388·3
K_1	156·1	355·1	479·4	423·7	353·6	307·9	399·2
	162·4	344·2	449·0	458·8	353·6	313·5	393·7
P_0	173·8	278·7	367·0	434·4	313·5		
P_1	151·0	409·8	531·0	483·2	393·7		

Least significant differences between two means at 5% level:

N.K. and N.P. tables	106·7
P.K. table and mean N	75·4
Other means	53·3

*Copies of tables showing the yields from individual cuts have been deposited at the places noted at the end of the paper.

TABLE 13. N.P.K. fertilizer trial on *Hyparrhenia* grassland: crude-protein content expressed as percentage of dry matter, 1957-8 season

First cut, 12.1.1958

	N_0	N_1	N_2	N_3		P_0	P_1
K_0	8·77	9·96	11·44	13·64	10·95	10·90	11·00
K_1	8·12	9·96	12·24	12·98	10·82	10·96	10·69
	8·44	9·96	11·84	13·31	10·88	10·93	10·84
P_0	8·54	9·60	11·09	14·50	10·93		
P_1	9·35	10·33	12·58	12·12	10·84		

Least significant differences between two means at 5% level:

N.K. and N.P. tables	1·69
P.K. table and mean N	1·20
Other means	0·84

Second cut, 28.4.1958

	N_0	N_1	N_2	N_3		P_0	P_1
K_0	4·57	4·72	5·23	5·64	5·04	4·87	5·21
K_1	4·86	5·47	4·70	5·03	5·02	5·17	4·87
	4·72	5·09	4·96	5·33	5·03	5·02	5·04
P_0	4·84	4·99	4·86	5·38	5·02		
P_1	4·60	5·20	5·06	5·29	5·04		

Least significant differences between two means at 5% level:

N.K. and N.P. tables	0·93
P.K. table and mean N	0·64
Other means	0·47

1957–8 season are shown in Tables 11, 12 and 13.

Sulphate of ammonia again increased yields of dry matter and crude protein but it was less efficient at the higher levels of application and the quadratic component of the effect was significant in the first cut and in the seasonal totals. However, the increase in percentage crude protein in the first cut was entirely linear and this was reflected in a linear increase in yield of crude protein up to the N_2 level, despite the non-linear increase in dry-matter yield above the N_1 level. (See Fig. 17).

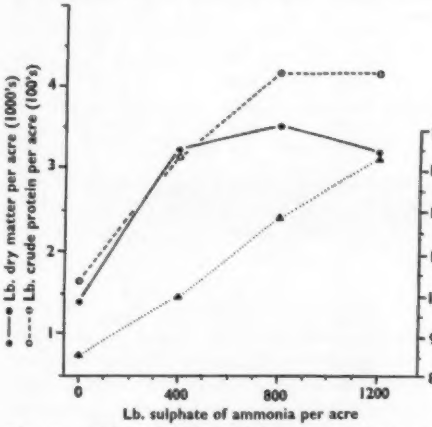

Fig. 17. N.P.K. fertilizer trial on *Hyparrhenia* grassland: mean responses to sulphate of ammonia in the first cut of the 1957–8 season.

Positive yield responses were obtained with superphosphate in the first cut of the season, but this fertilizer had no effect on percentage crude protein. Muriate of potash produced no significant effects.

Since the yield increments at the higher levels of sulphate of ammonia in the first year were small it was decided to alter the method of application in the second season to test whether more efficient utilization might be achieved with a split rather than a single dressing. Accordingly the herbage was cut 4 times during the season, at the 12 to 15 inch stage, and the sulphate of ammonia was applied in 4 equal dressings, one at the beginning of the rains and one after each of the first 3 cuts.

The dressings of sulphate of ammonia were increased in the second season and the rates of application of superphosphate and muriate of potash were raised in proportion to preserve the balance of added nutrients. The revised rates of fertilizer application were:

N_0—0 lb. sulphate of ammonia per acre.
N_1—500 lb. ,, ,, ,, ,, ,,
N_2—1000 lb. ,, ,, ,, ,, ,,
N_3—1500 lb. ,, ,, ,, ,, ,,
P_0—0 lb. superphosphate per acre.
P_1—500 lb. ,, ,, ,,
K_0—0 lb. muriate of potash per acre.
K_1—250 lb. ,, ,, ,, ,, ,,

The results in the second year (1958–9) of this trial are given in Tables 14, 15 and 16.

While the quadratic component of the response to sulphate of ammonia in terms of dry-matter yield was again significant in the 1958–9 season, the split dressing increased the efficiency of this fertilizer in that the response was linear up to a higher level than in the previous season with a single dressing. (See Fig. 18).

TABLE 14. N.P.K. fertilizer trial on *Hyparrhenia* grassland: (lb. dry matter per acre) 1958-9 season*

	N_0	N_1	N_2	N_3		P_0	P_1
K_0	1859	3241	4275	4915	3572	3233	3912
K_1	1902	3477	4602	4491	3617	3320	3915
	1880	3359	4438	4703	3595	3276	3913
P_0	1807	3279	3888	4132	3276		
P_1	1954	3438	4989	5273	3913		

Least significant differences between two means at 5% level		
	N.K. and N.P. tables	476
	P.K. table and mean N	336
	Other means	238

*Copies of tables showing the yields from individual cuts have been deposited at the places noted at the end of the paper.

TABLE 15. N.P.K. fertilizer trial on *Hyparrhenia* grassland: (lb. crude protein per acre) 1958-9 season*

	N_0	N_1	N_2	N_3		P_0	P_1
K_0	158	303	452	604	379	336	422
K_1	158	323	481	528	372	342	403
	158	313	466	566	375	339	413
P_0	149	293	414	502	339		
P_1	168	333	519	631	413		

Least significant differences between two means at 5% level:
- N.K. and N.P. tables 67
- P.K. table and mean N 47
- Other means 33

*Copies of tables showing the yields from individual cuts have been deposited at the places noted at the end of the paper.

TABLE 16. N.P.K. fertilizer trial on *Hyparrhenia* grassland. Crude protein content expressed as percentage of dry matter, 1958-9 season

First cut, 23.12.1958

	N_0	N_1	N_2	N_3		P_0	P_1
K_0	7·59	8·84	9·56	11·41	9.35	9·37	9·33
K_1	7·33	8·78	9·42	11·34	9·21	9·20	9·23
	7·46	8·81	9·49	11·37	9·28	9·28	9·28
P_0	7·36	8·34	10·20	11·26	9·28		
P_1	7·56	9·29	8·78	11·49	9·28		

Least significant differences between two means at 5% level:
- N.K. and N.P. tables 1·06
- P.K. table and mean N 0·75
- Other means 0·53

Second cut, 16.1.1959

	N_0	N_1	N_2	N_3		P_0	P_1
K_0	8·48	10·25	11·23	13·45	10·85	11·01	10·69
K_1	9·69	10·13	11·83	13·13	11·19	11·11	11·27
	9·08	10·19	11·53	13·29	11·02	11·06	10·98
P_0	8·87	9·97	11·83	13·59	11·06		
P_1	9·30	10·41	11·23	12·99	10·98		

Least significant differences between two means at 5% level:
- N.K. and N.P. tables 1·37
- P.K. table and mean N 0·97
- Other means 0·69

Third cut, 17.2.1959

	N_0	N_1	N_2	N_3		P_0	P_1
K_0	8·17	8·96	10·39	11·65	9·79	9·51	10·07
K_1	7·66	8·73	9·75	10·83	9·24	9·23	9·25
	7·91	8·84	10·07	11·24	9·51	9·37	9·66
P_0	7·71	8·49	9·92	11·37	9·37		
P_1	8·12	9·19	10·22	11·11	9·66		

Least significant differences between two means at 5% level:
- N.K. and N.P. tables 1·06
- P.K. table and mean N 0·75
- Other means 0·53

Fourth cut, 20.3.1959

	N_0	N_1	N_2	N_3		P_0	P_1
K_0	9·24	9·46	11·39	13·43	10·88	10·31	11·46
K_1	9·24	9·85	11·52	12·21	10·70	10·96	10·45
	9·24	9·66	11·46	12·82	10·79	10·63	10·95
P_0	9·12	9·15	11·29	12·98	10·63		
P_1	9·36	10·17	11·62	12·66	10·95		

Least significant differences between two means at 5% level:
- N.K. and N.P. tables 1·55
- P.K. table and mean N 1·09
- Other means 0·77

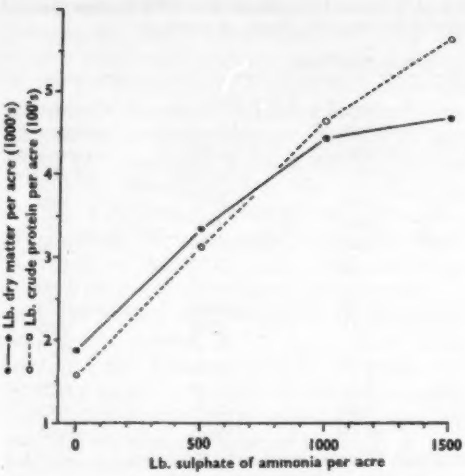

Fig. 18. N.P.K. fertilizer trial on *Hyparrhenia* grassland: mean responses to sulphate of ammonia in total yields of dry matter and crude protein for the 1958-9 season.

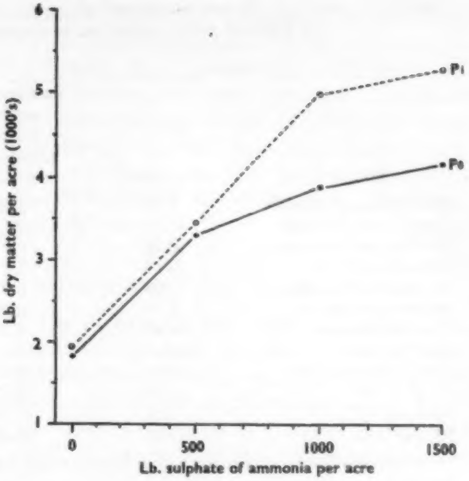

Fig. 19. N.P.K. fertilizer trial on *Hyparrhenia* grassland: interaction of sulphate of ammonia and superphosphate in total yield of dry matter for 1958-9 season.
P_0 = no superphosphate.
P_1 = superphosphate @ 500 lb. per acre.

Yield and percentage of crude protein increased linearly with the split dressing of sulphate of ammonia. Superphosphate produced significant yield responses in this second season, and there was a significant interaction between it and sulphate of ammonia because the superphosphate was more effective in combination with sulphate of ammonia. (See Fig. 19).

Muriate of potash depressed the percentage of crude protein in the third cut of the season and it had a negative interaction with sulphate of ammonia in the dry-matter yield from the first cut.

Table 17 shows the changes in total plant cover and botanical composition induced by dressings of sulphate of ammonia over two years in the N.P.K. trial. Cutting in combination with sulphate of ammonia was less effective than cutting alone in increasing vegetative cover. The reduction in cover compared to the cutting treatment without added nitrogen was directly proportional to the amount of sulphate of ammonia applied. With the exception of *Cynodon dactylon*, all the grass species showed a reduction in cover when nitrogen was added, compared to the simple cutting treatment. The legume *Tephrosia radicans* also decreased with the application of sulphate of ammonia.

DISCUSSION

The results of the present experiments on the *Hyparrhenia*-dominant grassland community agree with Pawson's (3) work on maize in showing that shortage of available nitrogen is a serious limiting factor in plant growth on the reddish-brown clay soils of the central region of Northern Rhodesia.

If the substantial shortage of nitrogen be remedied, phosphorus is the element in next shortest supply, and responses to dressings of superphosphate are largely conditional on the addition of nitrogenous fertilizer.

Both muriate of potash and agricultural lime had little effect on growth and production of this grassland community, at the levels tested, but there was an indication that both might depress yield; but further evidence is needed.

TABLE 17. Point quadrat determinations* of cover at ground level in *Hyparrhenia* grassland showing changes induced by repeated cutting, alone and in combination with dressings of sulphate of ammonia

	Percentage Cover				
Species	Untreated	Two years of cutting without nitrogenous fertilizer	Cutting plus sulphate of ammonia at Level (1)†	Cutting plus sulphate of ammonia at Level (2)†	Cutting plus sulphate of ammonia at Level (3)†
Hyparrhenia filipendula	1·71	4·20	2·60	2·67	1·60
Hyparrhenia dissoluta	1·33	1·67	0·93	1·00	0·87
Heteropogon contortus	0·38	0·93	1·00	0·40	0·40
Digitaria setivalva	0·14	1·87	1·87	1·27	1·53
Brachiaria brizantha	0·09	0·07	—	0·07	0·07
Setaria sphacelata	0·14	0·20	0·20	0·27	0·33
Cynodon dactylon	0·05	0·70	0·33	0·60	0·60
Other grasses	—	—	—	0·07	0·20
Tephrosia radicans	0·09	0·87	0·60	0·20	0·13
Other plants	0·09	0·27	0·33	0·20	0·20
Total cover	4·02	10·78	7·86	6·75	5·93
Bare ground	95·98	89·22	92·14	93·25	94·07

*The determinations were made with a frame having 5 points spaced 12 inches apart and 1500 points were recorded.

†Level (1) 400 lb. of sulphate of ammonia per acre applied as a single dressing at the beginning of the wet season in the first year and 500 lb. per acre in the second year in 4 equal dressings.

Level (2) 800 lb. sulphate of ammonia per acre as a single dressing in the first year and 1000 lb. per acre in the second year in 4 equal dressings.

Level (3) 1200 lb. of sulphate of ammonia as a single dressing in the first year and 1500 lb. in the second year in 4 equal dressings.

The form of the nitrogen-response curve depends on how the nitrogen is applied and whether it is in combination with superphosphate. Splitting the nitrogen dressing and the addition of superphosphate resulted in linear yield responses up to an annual level of 1000 lb. of sulphate of ammonia per acre.

While the yield responses to nitrogen application were quadratic at the highest levels, the percentage of crude protein in the herbage increased linearly up to 1500 lb. of sulphate of ammonia per annum. This may reflect a linear increase in true protein, but the possibility of accumulation of nitrogen in an inorganic form cannot be excluded as crude-protein content was estimated by the Kjeldahl method.

III. THE EFFECT OF FIRE

INTRODUCTION

Trapnell (6) pointed out that the open *Hyparrhenia*-dominant grassland community in the Mazabuka district is a fire-climax. He noted that woody species colonized fire-protected sites and that the tall *Hyparrhenia* species were ousted in favour of a sparse cover of shade-tolerant grasses.

In recent years many formerly open *Hyparrhenia* grasslands in the central region of Northern Rhodesia have been colonized by tree species. This process has occurred on the extensive cattle ranches in the European areas where grazing management has been lax, and also in the African areas where much of the former grazing land has been cultivated for maize production. In some cases fire has been deliberately excluded, but more often indiscriminate grazing has so reduced the amount of combustible grass material that the sporadic grass fires which occur are ineffective in preserving the balance between grass and tree species.

West (9) asserted that for a grass fire to be of maximum benefit in preventing colonization by woody plants it must occur late in the dry season when these plants are actively growing in the pre-rains flush and while the grasses are still largely dormant. He also stated that there should be a maximum accumulation of dry grass to burn. The latter condition implies protection from grazing in the previous wet season, so that all the grass growth is available for burning. West suggested that in Southern Rhodesia a deliberate burn satisfying these conditions might be necessary every 4 years in order to prevent colonization of the grassland by the tree species. If the grassland is burnt every 4 years following protection during the growing season a quarter of the grazing area will be tied up for this purpose. The object of the first experiment reported here was to test possible alternative treatments to fire which did not involve this enforced rest.

In addition to controlling bush encroachment, burning this type of grassland late in the dry season induces a flush of new grass before the normal regrowth takes place at the beginning of the rains. The second experiment described below was designed to investigate this phenomenon.

BURNING TO CONTROL BUSH ENCROACHMENT

The experiment was sited in a *Hyparrhenia* grassland paddock at the Mount Makulu Central Research Station. The paddock had been used for grazing and haymaking for 5 years, and fire had been excluded during that time. Before enclosure and protection the

TABLE 18. Changes induced in the tree-seedling population of *Hyparrhenia* grassland by burning and other treatments over one year

		Number of seedlings per acre			Average length of leading shoot in inches		
Treatment	Woody species	December 1955	December 1956	% Change	December 1955	December 1956	% Change
(i) Rested during wet season 1955–6 and burnt in October 1956	*Acacia sieberiana*	3024	32	−98·9	15·9	33·6	+111·3
	Other woody species	228	196	−14·0	12·1	35·7	+195·0
	Total	3252	228	−93·0	15·7	35·4	+125·7
(ii) Mown in February and April 1956	*Acacia sieberiana*	3680	2640	−28·3	18·1	11·8	−34·8
	Other woody species	140	120	−14·3	17·0	10·6	−37·6
	Total	3820	2760	−27·7	18·0	11·7	−35·0
(iii) Woody plants hoed out at ground level in February and April 1956	*Acacia sieberiana*	3220	2772	−13·9	22·7	15·6	−31·3
	Other woody species	128	68	−46·8	18·8	15·5	−17·5
	Total	3348	2840	−15·2	22·2	15·6	−29·7
(iv) Woody plants sprayed with 2% 2,4,5-T in water at the rate of 25 gallons per acre April 1956	*Acacia sieberiana*	2420	1900	−21·5	14·9	23·7	+59·1
	Other woody species	96	80	−16·7	13·0	16·5	+27·0
	Total	2516	1980	−21·3	14·8	23·4	+58·1
(v) Control, not treated	*Acacia sieberiana*	1920	1496	−22·1	21·2	36·8	+72·0
	Other woody species	160	140	−12·5	18·9	36·5	+93·1
	Total	2080	1636	−21·4	21·2	36·7	+73·1

grassland community had an open aspect with a few scattered shrubs, mainly species of *Terminalia* and *Combretum*. After 5 years' use a dense crop of young *Acacia* seedlings had developed. The treatments superimposed on this population of 2- to 3-years-old seedlings were late-burning, mowing, hoeing out at ground level, and spraying with a 2% solution of 2,4,5-T. Unreplicated plots, each of a quarter of an acre, were used. Table 18 shows the effects of these treatments over the first year of the trial.

Late burning was effective in reducing the population of tree seedlings over the first year but changes in the plots receiving the other treatments differed little from the control, except that the purely mechanical effect of mowing and hoeing out at ground level was reflected in the reduced height of the seedlings. The position was unchanged at the end of the second year. Treatments other than burning had no effect relative to the control, apart from the reduction in stature on the mown and hoed plots. Examination of *Acacia* seedlings on another site which had been mown at least twice each growing season for 7 years showed that they had well-developed root systems which extended more than 6 feet below the surface. A boss of woody tissue had developed at, and just below, the soil level and up to 9 new shoots were produced from this point within 4 weeks of mowing. It was concluded that these seedlings are tolerant of repeated removal of the aerial parts and that there is little hope of controlling them in this way. Spraying with 2,4,5-T, as carried out in the trial, was also ineffective, but further work on the type of spray, its application and timing will be necessary before this potential means of control can be evaluated adequately.

Apart from the possibility of using a selective chemical spray it appears that burning offers the only effective alternative to ploughing or digging out the encroaching woody species.

BURNING TO INDUCE PRE-RAINS GROWTH

Table 19 illustrates the yields of new grass growth which were obtained from unreplicated quarter-acre plots of *Hyparrhenia* grassland burnt in the second half of the dry season. The plots were rested during the wet season in each year and the regrowth after burning was harvested by hand.

The quality of the regrowth after burning, as indicated by the crude-protein content, was high for this type of grassland. However, the yields of herbage were very low, except in the case of the last-burnt plot in the first year of the experiment which had an appreciable quantity of rain in the period between burning and harvesting the regrowth. Prolonging the period between burning and harvesting from one month to two months had little effect on the bulk of herbage produced.

TABLE 19. Yields and chemical composition of the regrowth after burning *Hyparrhenia* grassland

Year	Date of burning	Interval between burning and sampling	Rain during growth period, in inches	Dry-matter yield, pounds per acre	Percentage crude protein on a dry-matter basis
1956	8 Aug.	One month	Nil	7·8	7·2
	8 Sept.		Nil	10·7	10·1
	8 Oct.		0·31	12·5	9·6
	7 Nov.		7·89	178·4	11·6
1957	6 July	One month	Nil	8·1	9·0
	7 Aug.		Nil	8·5	9·0
	7 Sept.		0·96	8·5	12·3
	8 Oct.		1·08	8·8	13·4
1958	7 Aug.	One month	Nil	4·7	8·2
	7 Aug.	Two months	0·02	9·1	8·5
	8 Sept.	One month	0·02	7·9	8·2
	8 Sept.	Two months	2·44	7·7	10·4
	10 Oct.	One month	2·42	9·4	12·3

Burning depressed the yields of herbage obtained in the succeeding wet season (see Table 20). It is suggested that this depression resulted from the depletion of root reserves in the "false start" induced by burning before moisture was available for sustained growth.

TABLE 20. Yields of herbage from *Hyparrhenia* grassland in the wet season following burning. (Unreplicated quarter acre plots)

Date of burning	7 Aug. 1958	8 Sept. 1958	10 Oct. 1958	Control, not burnt
Lb. dry matter per acre, on 20 Feb. 1959	3119	3081	2690	3866

Changes in plant cover at ground level after burning in the late dry season for 3 years are shown in Table 21.

TABLE 21. Point-quadrat determinations of cover at ground level in *Hyparrhenia* grassland showing changes induced by late burning over three years

Species	Percentage cover before burning treatment	Percentage cover after burning treatment
Hyparrhenia filipendula	4·14	2·90
Hyparrhenia dissoluta	0·14	0·24
Brachiaria brizantha	0·38	0·09
Heteropogon contortus	0·14	0·28
Cynodon dactylon	0·24	0·24
Other grasses	0·33	0·38
Tephrosia radicans	1·09	0·38
Other plants	0·81	0·62
Total cover	7·27	5·13
Bare ground	92·73	94·87

The decrease in total plant cover after the burning treatment was accompanied by a marked compaction of the soil between the tussocks and these changes would probably increase susceptibility to sheet erosion.

As Trapnell (6) remarked, burning has no great effect on the specific composition of the community, though the decrease in the legume *Tephrosia radicans* is noteworthy. The figures also show that *Hyparrhenia dissoluta* is more tolerant of repeated burning than *H. filipendula*. The decrease in *Brachiaria brizantha* agrees with Trapnell's observation that this grass increases with protection from fire.

DISCUSSION

Trapnell (6) stated that "fire is to be regarded as a necessary evil rather than an instrument of management" in this type of grassland. He noted that burning might be useful to remove dead herbage and to control the encroachment of *Acacia* spp. West (9) said that fire should be used to maintain the balance between grass and tree species in the lower rainfall areas of Southern Rhodesia, where production per acre is very low, and the only economic form of land usage is ranching on an extensive scale. But he suggested that it would be inappropriate in higher rainfall regions where more intensive production is possible. The present results confirm that a burn late in the dry season is effective in controlling the encroachment of *Acacia* spp. in this type of grassland. But they show that if practised frequently it will lead to decreased plant cover and compaction of the surface soil. Since an effective burn also involves the loss of a year's grazing on the area to be treated and the amount of out-of-season grazing produced is negligible, its use should be avoided where possible. As the greater part of Northern Rhodesia has a rainfall in excess of 30 inches, there is no climatic limitation to intensive grassland husbandry such as West instanced in parts of Southern Rhodesia. If the potential production is to be achieved, however, an economic alternative to the use of fire in controlling bush encroachment must be found.

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THE EFFECT OF NITROGENOUS FERTILIZER ON AN ESTABLISHED WHITE CLOVER SWARD

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The effect of nitrogenous fertilizer on a white clover sward was studied to obtain information to be used in the evaluation of white clover in grassland. There was no evidence of a yield response. The weight of nodules was depressed by the addition of fertilizer.

Where management is adjusted to maintain white clover in swards receiving large quantities of nitrogenous fertilizer the clover may use part of this fertilizer at the expense of symbiotic fixation.

The relation of the results obtained to the assessment of the benefit derived from white clover in mixed swards is briefly discussed.

INTRODUCTION

When one has to interpret the results of experiments in which nitrogenous fertilizer is applied to grass/legume swards, it is useful to know how the constituent species react to the fertilizer when grown by themselves. Our knowledge of the effect of nitrogen on legumes is mainly derived from annual species or from pot work with the young developing plant. There appears to be little evidence available on white clover. Allos and Bartholomew (1) included white-clover seedlings in pot studies and found that their yield was increased by the addition of nitrogen. At all rates of application, except the lowest, the amount of nitrogen fixed was depressed. Walker *et al.* (7), using rather older seedlings in pots, concluded that yield was depressed at the lowest rate of added nitrogen but increased at the highest rate. Brown and Munsell (3) report that 30 lb. of nitrogen per acre applied to a pure, sown white-clover sward depressed yield; it is not stated whether differential weed-growth affected the result.

The two experiments reported in this paper were designed to study the reaction of established white clover to dressings of inorganic nitrogenous fertilizer.

METHODS AND MATERIALS

The first experiment was carried out in 1958 on a sward of Aberystwyth S100 white clover, sown pure in spring 1957. The clover was hand-weeded throughout the year of sowing and the first winter. In the spring it received a uniform dressing of 134 lb. K_2O (as muriate of potash) and 40 lb. P_2O_5 (as superphosphate) per acre. Sixty-four small plots provided 8 randomized blocks with 8 treatments. The treatments were 0, 35, 105 or 210 lb. N per acre (as nitro-chalk, 15·5% N) applied in two equal dressings in either the first and third or the second and fourth periods of growth. These periods were arbitrarily chosen and ended with cuts on 21 May, 3 July, 26 August and 15 October. The initial fertilizer dressing was applied on 1 April. Systematic hand-weeding ceased a fortnight later. Fertilizer was subsequently applied after cutting. Hand shears were used to harvest a 4 ft. × 3 ft. quadrat, which allowed a discard 1 ft. wide around the sample area. Fresh and dry weights for each plot and the nitrogen content of a representative sample for each treatment were determined on each occasion. Botanical separation was carried out on a sub-sample from every plot at the third and fourth cuts, by which time weed species contributed more than 5% of the yield. Rainfall was above average in 1958; although there was a soil moisture deficit in early May, subsequent precipitation was sufficient to replace evapotranspiration.

In 1959, as a sequel to this experiment, two soil monoliths and a number of core samples were taken from white-clover swards and the distribution of roots and nodules was examined. The two monoliths, 12 in. × 6 in. × 2 ft. deep, were from swards which had received very different treatments in the previous year. In the two cases 82% and 98% of the nodules were found in the top 3 inches. No replication was possible because of the laborious nature of the work. A limited number of samples of various surface areas, taken to a depth of 3 in., suggested that a 3-in. diameter core was reasonably satisfactory.

A second experiment was then carried out in which the effect of a single dressing of fertilizer on clover top- and root-growth was measured. Two treatments, a control and 100 lb. N per acre, were replicated 6 times on small plots. The fertilizer was applied after thorough irrigation on 27 July and the plots were harvested on 25 August. Roots and above-ground portions not harvested as herbage were sampled by taking two 3-in. diameter cores per plot to a depth of 3 in. These samples were washed, using the apparatus described by Williams and Baker (9), with further decantation to remove most of the organic matter other than clover. The material so obtained was stored at 5°F and subsequently stolons, roots and nodules were separated and the dry weight and nitrogen content determined.

RESULTS

The yield of white clover in the first experiment is shown in Table 1. In the total yield and in three of the individual cuts, differences due to treatment did not reach significance at the $p=0{\cdot}05$ level. In the August cut a difference was indicated. The application of nitrogen at the highest level appears to have reduced yield below that of most of the other treatments.

In the third and fourth cuts the figures given in Table 1 refer to the white-clover fraction of yield. When the yields, including weed species, from each of these two cuts were analysed, a significant difference between treatments was detected only in the fourth cut. This could be attributed to the response of invading weed species to the fertilizer. The effect was not sufficient to show significant differences

TABLE 1. Yield of white clover herbage
Dry matter, grams per 12 sq. ft.

Fertilizer treatment	Nitrogen lb./acre	May	July	Aug.	Oct.	Total	Total (including weeds)
Applied before 1st & 3rd cuts	0	217	287	252	107	863	901
	35	209	286	259	119	873	922
	105	200	297	254	111	862	899
	210	189	305	221	115	830	898
Applied before 2nd & 4th cuts	0	217	294	236	125	872	909
	35	207	289	243	127	866	926
	105	185	290	252	121	848	905
	210	216	278	264	120	878	927
S.E. of mean of 8		±14·2 NS	±8·45 NS	±8·9 *	±4·9 NS	±19·0 NS	±23·6 NS

TABLE 2. Dry weight of various fractions harvested from a white-clover sward
Grams per 3-in. diameter core. (Nitrogen content of tops shown in brackets)

Treatment	Leaf and petiole*	Stolon and petiole base	Root (to 3 in. depth)	Nodules (to 3 in. depth)
No nitrogen	0·810 (4·49)	2·29 (2·96)	0·927	0·035
Nitrogen (100 lb./per acre)	0·804 (4·36)	2·13 (2·56)	0·702	0·019
S.E.	NS	NS	NS	±0·0025**

*Derived from 6-sq. ft. samples

between treatments when total annual yield, including weed species, was examined (final column of Table 1).

The nitrogen content of the harvested clover, which did not vary greatly with treatment, averaged 4·39%, 3·72%, 4·04% and 4·52% at the 4 cuts. Flower heads were numerous at the second cut.

The results of the second experiment, in which the effect of a single dressing of fertilizer was studied, are given in Table 2. There was no significant difference in above-ground fractions of clover between the two treatments. The low value for root weight where nitrogen was applied was due mainly to a very low weight in one replicate; the difference between treatments was not significant ($p=0{\cdot}05$).

A significant difference ($p=0{\cdot}01$) was established in the weight of nodules; the treated plot gave the lower value.

The nodule/root ratio was significantly higher on the untreated plots ($p=0{\cdot}05$).

DISCUSSION

In the two experiments under field conditions neither the yield nor the nitrogen content of white clover was raised by dressings of nitrogenous fertilizer. The decrease in yield under the high nitrogen treatment in the August cut may have been due to fertilizer scorch, although this was not apparent in the field. It was barely significant ($p=0{\cdot}1$) and no great importance is attached to it.

Although increases in yield of white clover have been reported under pot conditions (1, 7), it seems unlikely that the yield of established, nodulated white clover will be increased under field conditions with the levels of nitrogenous fertilizer commonly used in agriculture. Usually white clover is grown in a mixture with grasses and under these conditions its yield is depressed when fertilizer nitrogen is added. Blackman (2) discussed this suppression and concluded that it was due primarily to competition from the grasses rather than to a direct effect of the fertilizer on clover.

Both Williams (8) and Young (10) have reported a beneficial effect of nitrogenous fertilizer on white clover in mixed swards in the early spring. That this might be a direct effect on the clover is not supported by the present data nor by observations made before the first cut.

It is possible that in the present experiments part of the applied nitrogen may have been taken up by clover. The depression of nodule weight detected in the second experiment was not accompanied by a decrease in yield of herbage. Using ^{15}N under pot conditions Allos and Bartholomew (1) and Walker *et al.* (7) have demonstrated the partial replacement of the fixation process in white clover by applied nitrogen.

The decrease in nodule weight per gram of root where nitrogenous fertilizer was applied would be expected, in view of the evidence available from a large number of sources, recently quoted by Van Schreven (6). In the mixed sward, Young (10) reported the failure of heavy dressings of fertilizer to reduce the number of nodules per gram of root. She concluded that this resulted mainly from the strong competition for nitrogen by the grass. Whether this would remain true where management was designed to retain clover in the presence of high nitrogenous fertilizer usage is uncertain.

In practice there is a tendency for the mixed sward that receives nitrogen to show a decline in the proportion and in the absolute yield of white clover. It is generally accepted that the fall in proportion may be arrested by more frequent harvesting. Such management may lead to a position where the clover would utilize a greater proportion of applied fertilizer nitrogen.

It seems probable that a great part of the benefit derived by grass growing in association with clover is due to the decay of older clover organs. The suppression of clover in a sward may lead to a release of nitrogen which may have a considerable effect on grass yield. In the long term, both the direct contribution of clover and its continued indirect benefit would, however, be lost.

In this context it is interesting to note the large amount of stolon present and the low root/top ratio in the clover sward. The latter point was also noted by Young (10). It is important to obtain more information about the rates of growth and decay of clover under sward conditions if the plant is to be fully exploited. Stolon decay may be responsible for a large part of the benefit attributed to subsurface transference of nitrogen in the mixed sward. In other words, some of the benefits of white clover may lie in the fact that the plant is incompletely harvested. At the time of sampling in the second experiment, which followed a 6-week period of rapid growth resulting in 1600 lb. per acre of herbage dry matter, the amount of nitrogen in the underground organs was estimated to be 47 lb. per acre. The nitrogen in the stolon and unharvested petiole was 133 lb. per acre.

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DIFFERENTIAL SURVIVAL OF CULTIVARS OF *LOLIUM, DACTYLIS* AND *PHLEUM*

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A study of plant establishment showed that a considerable depletion in the size of the grass population occurred during the first few months after sowing. In this experiment, two months after reseeding, the surviving grass seedlings amounted to about 20% of the viable seed sown; this figure was further reduced to about 10% before the swards were twelve months old.

In swards based on several cultivars within a species the casualty rate varied from cultivar to cultivar, and may be further modified by manuring and management.

Evidence from older swards indicated that within a period of six years one cultivar could suppress another almost completely.

The data suggest that not only is there a strong selection pressure within a sward during its early life, but also that the environment (produced in this case by manuring and management) determines the relative persistency and aggressiveness of the individual cultivars. This illustrates how a sward originally composed of several plant types eventually settles to a narrow range, provided the management is not varied.

Collections of grasses from various locations, as exemplified in the work of Stapledon with *Dactylis* spp., show that plant type in the main is characteristic of the habitat. A large proportion of plants derived from old grazed pastures are high tillering, dense and late-flowering, while those from temporary leys for seed production are lax and early-flowering. As a result of a close study of economically important herbage plants, the limiting and selective effect of environment has repeatedly been inferred (2, 3, 7). There is, however, no published information in which the course of differential survival has been followed. The facilities available at Aberystwyth have made it possible to carry out such an investigation. Distinct, easily-recognizable cultivars of *Lolium* spp., *Dactylis* spp. and *Phleum* spp. are available as a result of many years of forage breeding. In addition, there are also agronomic techniques developed over an equally long period of research.

The dynamic nature of grass swards and the rapid adjustment of the balance between grass and clover and between different species of grass have often been demonstrated (4, 6). This paper is concerned with the effects of agronomic selection pressures, particularly during establishment, on mixtures of grass varieties.

MATERIAL AND METHODS

The species and cultivars used were:

Lolium mixture

Lolium multiflorum (S22) from ordinary commercial stock selected for persistency and leafiness.

Early-flowering *Lolium perenne* (S24) bred from material collected from lightly-grazed pastures.

Late-flowering *Lolium perenne* (S23) based mainly on material from old fattening pastures in Kent, the Midlands, and elsewhere, but always from very old grazed pastures.

Dactylis mixture

Early-flowering *Dactylis glomerata* (Danish), a lax erect hay type resulting from many generations of seed, taken mainly in the first and second harvest years from leys which were not grazed hard or grazed early.

Late-flowering *Dactylis glomerata* (S143) a dense leafy prostrate type based on material collected from grazed swards.

Phleum mixture

Early-flowering *Phleum pratense* (Bd 2308) an erect hay type.

Medium late *Phleum pratense* (S48) a dual-purpose type suitable for hay or rotational grazing based on plants collected from lightly grazed areas.

Phleum nodosum (S50) a prostrate narrow-leaved type from material collected from very old pastures of the highest grazing reputation in the Midlands and Kent.

Mixtures (lb./acre)

Lolium		*Dactylis*		*Phleum*	
S22	8	Danish	8	Bd 2308	6
S24	8	S143	8	S48	4
S23	8			S50	4

Trifolium pratense (broad red) at 3 lb./acre and *T. repens* (commercial) at 1 lb./acre were included in all mixtures. The mixtures were sown on 21 March 1958 as main plots in a split-plot randomized-block with 4 replications. Superphosphate (18% P_2O_5) at 3 cwt./acre and muriate of potash (60% K_2O) at 1 cwt./acre were given to all plots at time of sowing.

Three managements were applied to each main plot:

1. Frequent grazing. Grazed 5 times in the seeding year, no cover crop.
2. Infrequent defoliation. Cut 12.8.58, grazed in autumn, no cover crop.
3. Herbage sown under oats harvested for grain when fully ripe, and grazed in autumn.

There were two levels of nitrogen:

N_0=no nitrogen

N_1=N applied as nitro-chalk at 52 lb./acre.

Plants were removed from each plot at intervals of 2 months, 5 months and 11 months after sowing, grown-on as single-plant units (3 rows of 17 plants each) in a split-plot randomized-block, and classified into the cultivars. The treatments were laid out in a manner similar to the swards from which the single plants had been removed, a total of nearly 12,000 single plants being involved. The reality of the differences in growth form between cultivars was readily apparent from the check rows of the eight cultivars randomly distributed in the lay-out, where they could constantly be referred to at all stages of growth and in all seasons. Classification of growth form was supplemented by data on head

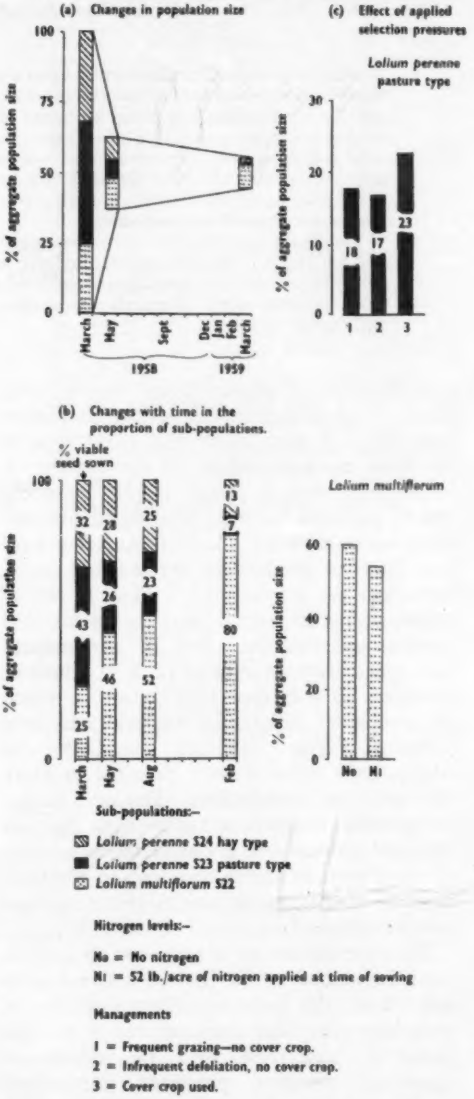

Fig. 1. Changes in *Lolium* populations during establishment.

emergence and plant height. The percentage of viable seed can be seen in Figs. 1, 2 and 3.

In addition to the main trial, data from experiments with *L. perenne* at three other centres are included (see section on Selection in established swards).

RESULTS

Selection of cultivars in the Lolium mixture

The enormous decrease in the total population size (averaged over all treatments) during establishment is illustrated in Fig. 1 (a), when 25% of the viable seeds sown produced plants which survived two months after sowing, whereas only 11% survived the first winter in the sward.

The size of all sub-groups within the *Lolium* population did not decrease to the same extent, Fig. 1 (b). The rapid-establishing S22 dominated the swards, contributing 46% shortly after sowing, but 80% nine months later. Both the early- and late-flowering *Lolium perenne* contributed less to the total population as the sward became older, the mean recorded figure for S24 was 13% and that for S23 only 7%.

In addition to the general shift with time in the proportion of ryegrass cultivars, management also had an effect in that the percentage of late-flowering ryegrass was higher when a cover crop was used. When nitrogen was applied, Italian ryegrass contributed a slightly lower proportion to the total grass plants; this was unaffected by the cover crop or the frequency of defoliation. The statistically significant differences are given in Table 1.

Selection of cultivars in the Dactylis mixture

The high mortality occurring during establishment is illustrated in Fig. 2 (a). Fig. 2 (b) shows that during this period the hay type of *Dactylis* dominated all swards with a mean figure of 72%. The proportion of pasture and hay types was modified by management, e.g., the cover crop reduced the proportion of Danish cocksfoot 8 weeks from sowing. The percentage of S143 increased from the first sampling to 5 months after sowing when grazing was frequent, but under a cover crop, or when defoliation was infrequent, this did not occur.

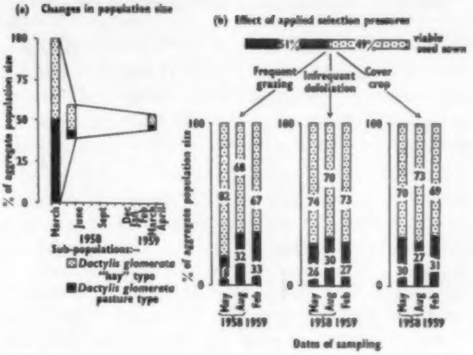

Fig. 2. Changes in *Dactylis* populations during establishment.

Selection of cultivars in the Phleum mixture

As in the *Lolium* and *Dactylis* populations, a marked decrease in overall population size occurred in the seeding year; only 7% of the viable seed sown produced plants which survived the first winter (Fig. 3 (a)).

The average proportion of the erect early-flowering cultivar Bd 2308 did not change very much with increasing age of the sward (Fig. 3 (b)) and the mean figure averaged over

TABLE 1. Percentages of each cultivar in the *Lolium* population, angular transformation (actual percentages shown in Fig. 1)

Date of sampling	Change with time			Effect of management on S23			Effect of nitrogen on S22	
	S22	S24	S23	Freq. graz.	Infr. def.	Cover crop	N_0	N_1
May	42·7	31·7	30·6					
Aug.	46·1	30·1	28·3	23·9	23·6	27·1	52·8	49·1
Feb.	64·1	19·8	14·7					
L.S.D.								
P=0·05	4·0	4·5	3·1		2·8		3·4	

TABLE 2. Percentages of each cultivar in the *Dactylis* population, angular transformation (actual percentages shown in Fig. 2)

Date of sampling	Danish Freq. graz.	Danish Infr. def.	Danish Cover crop	S143 Freq. graz.	S143 Infr. def.	S143 Cover crop
May	65·2	60·1	57·3	24·8	29·9	32·7
Aug.	56·3	57·5	58·8	33·8	32·5	31·1
Feb.	55·5	59·0	57·0	34·6	29·6	33·7
L.S.D. for rows P=0·05		5·5			5·5	
L.S.D. for cols. P=0·05		9·1			6·6	

all dates was 42%. In contrast to this the extreme pasture type S50 decreased from 44% 2 months after sowing, to 30% at the second sampling date 5 months after sowing. The dual-purpose S48 timothy increased in all swards from the initial figure of 17% to 31% eleven months after seeding.

This general picture was modified by the application of nitrogen and the management of the sward (Fig. 3 (c)). The proportion of pasture variety S50 was less under lenient defoliation without a cover crop than when a cereal was sown. The proportion of the pasture type under a cover crop, however, was not significantly higher than the frequently grazed sward seeded without a cereal. The number of plants of the erect early-flowering hay cultivar Bd 2308 was higher under Management 2 than under Managements 1 and 3.

The application of nitrogen decreased the contribution of *Phleum nodosum* S50 to the total number of grass plants present when grazing was frequent. Under the cover crop, or when defoliation was infrequent, nitrogen had no significant effect.

Selection in established swards

Evidence was also obtained from established swards on changes which occur in the proportion of early- to late-flowering cultivars of *Lolium*. Data were collected from three centres, two from commercial farms, Penwenallt and Bwlchcrwys, where the management was under the control of the farmers; the third was on Frongoch, the experimental farm of the W.P.B.S., where all plots were individually fenced and grazed on a strictly rotational basis.

Relative yields obtained in the spring from *Lolium* mixtures are shown in Table 4 (a). In the second harvest year the early-flowering cultivars S24 and Irish produced more than the late-flowering S23, and the mixtures of early + late were influenced by the early-growing cultivars. In the fourth harvest year only the bred strain, S24, increased the yield of early + late *Lolium*, In 1955 (fifth harvest year) the yield of Irish ryegrass was much lower than that of S23, but the mixture of S23 + Irish was dominated by S23 (only 5% of early-flowering types survived in this sward at this time) and the yield was similar to that of the late-flowering cultivar.

In established grassland the individual plants cannot be identified and the grass population can be regarded as a number of

TABLE 3. Percentages of each cultivar in the *Phleum* population, angular transformation (actual percentages shown in Fig. 3)

Date of sampling	Change with time			Effect of nitrogen and management on S50			Effect of management on Bd 2308	
	S50	S48	Bd 2308		N_0	N_1		
May	41·4	24·2	38·6	Freq. graz.	38·6	30·7	Freq. graz.	39·4
Aug.	32·4	27·9	43·5	Infr. def.	30·0	32·6	Infr. def.	46·1
Feb.	29·1	33·3	41·8	Cover crop	38·5	36·6	Cover crop	38·6
L.S.D. P=0·05	7·8	5·5	n.s.		5·6			4·0

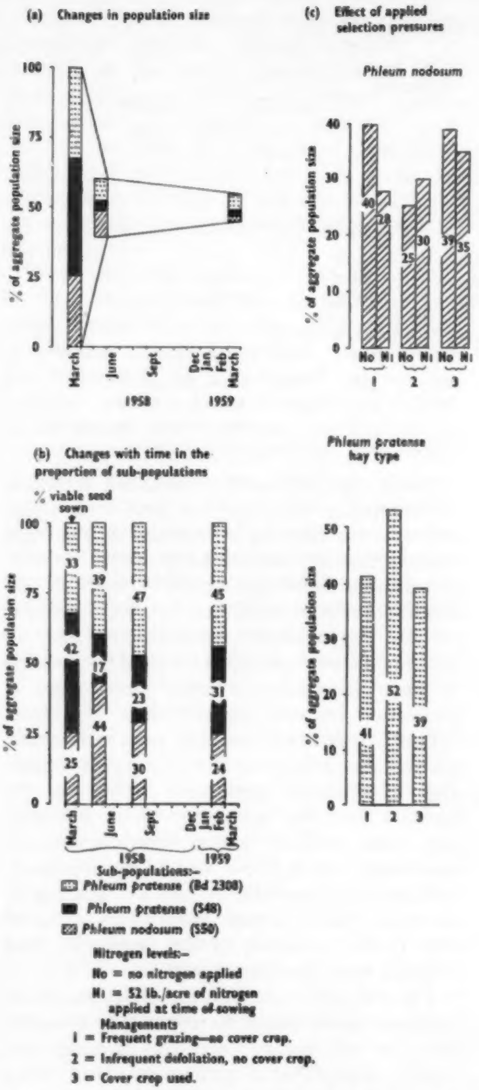

Fig. 3. Changes in *Phleum* populations during establishment.

tillers. At the three centres shown in Table 4 (b), 400 spaced plants were obtained from random sampling tiller units in each mixture. The single plants were classified as early- or late-flowering and it can be seen that the late-flowering cultivar dominated the swards. This occurred even though during establishment the quicker growing hay types were at an advantage, and all the varieties showed good persistency when sown separately. The data in Table 4 (c) show, on the basis of tiller counts and yield, the persistency of the early-flowering cultivars compared with S23 when sown separately. In addition, it can be seen that S24 sown with S23 was able to persist in a mixture with S23 to a far greater extent than Irish ryegrass sown with S23 (Table 4 (b)).

DISCUSSION

Individual plants compete with each other for nutrients, room to grow and to reproduce. The situation in grassland is, however, rather different as, in marked contrast to the very uniform plant types found in cereals and other arable crops, swards are often composed of species embracing a wide range of ecological types. Amongst important type differences in herbage may be mentioned the speed of growth from seed, earliness of growth in spring, and the proportion of total leaf removed at any given height of defoliation. These factors can interact with grazing management, environment, climate, etc.

The high overall death-rate of grass plants during establishment has often been demonstrated. The wide differential mortality of the cultivars used in this investigation, provides a means whereby selection can occur. This can result in adaptation to the environment produced by management, fertilizer application or the interaction of both.

Selection pressure operates in a short space of time during establishment; the use of a cover crop reduced the proportion of plants which grew quickly from seed. This was detected in the *Dactylis* population only 8 weeks after sowing, and during the early part of this short period there could have been little competition between plants to bring about a selection pressure to cause this shift. The effect of the cover crop in checking the early-flowering hay types was also seen in the *Lolium* and *Phleum* populations.

TABLE 4. Selection of cultivars in established swards

(a) *Relative spring yields of ryegrass at a lowland centre (Frongoch) (S23=100)*

Harvest year	Late-flowering S23	Early-flowering S24	Early-flowering Irish	S23/S24	S23/Irish
Second	100	131	128	119	123
Fourth	100	147	120	128	98
Fifth	100	105	65	97	92

(b) *Percentage of early- and late-flowering Lolium in swards*

		S23/Irish	S23/S24
Fourth	Lowland centre: Penwenallt	81/19	53/47
Fifth	„ „ Frongoch	95/ 5	66/34
Sixth	Upland centre: Bwlchcrwys	99/ 1	97/ 3

(c) *Persistency of early-flowering Lolium when sown without a late-flowering cultivar*

		S23	Irish	S24	
Fourth	Lowland centre: Penwenallt	690	345	430	tillers per sq. ft.
Sixth	„ „ Frongoch	74·0	35·1	66·1	Annual yield of dry matter in 100 lb./acre
Sixth	Upland centre: Bwlchcrwys	55·0	33·8	41·4	

In the period from May to August the proportion of pasture cocksfoot without a cover crop increased when grazed four times, but when not grazed it did not do so, with or without a cover crop. The importance of plant type in relation to the biotic factor can be illustrated by the following data. Defoliating a sward of Danish cocksfoot in the spring by mowing machine, with the knife set at 1·5 in. above ground, removed 86% of the herbage obtained when cut with hand clippers to 0·5 in., whereas in the pasture S143 the corresponding figure was only 39%. It is not surprising therefore that regular grazing, which removes a far greater portion of the shoots of the erect plants, favours the prostrate or pasture type of plant.

Early-growing varieties have an initial advantage over late varieties in that they establish themselves better from seed (7). This was seen in the *Lolium* population, when S22 dominated the sward, and in the *Dactylis* population, when Danish had a higher number of plants than the late-flowering type, and also in *Phleum*, when Bd 2308 increased during establishment at the expense of the late-flowering cultivars. The evidence from the *Lolium* swards studied after establishment shows how the late-flowering cultivars can dominate eventually, even though the early cultivars have an initial advantage.

During establishment tremendous depletion of biotypes occurs, but the data from older swards show that the differential survival can result in further marked changes in the population in established grassland. A study of the balance between cultivars in swards under various agricultural managements, and in different locations, has proved ideal for demonstrating the changes whereby plant types in grassland become characteristic of their habitat. Under managements such as frequent grazing, the production of seed is not favoured, and selection of genotypes suited to the location and the prevailing biotic influence can occur without sexual reproduction. In conditions which allow seed to be produced, such as in a hay field, or hay and grazing in alternate years, sexual generations coupled with further selection of the variability thus released must also play a part.

The change in the balance of legume/grass and grass/grass species in response to management is well known, and this investigation clearly shows that a similar situation exists when cultivar/cultivar ratios are considered. It is logical to expect changes in the balance of types which exist within cultivars; such changes have been known to occur during seed production (1, 8) and by selection in the sward (5). The data collected in this trial on intra-cultivar variation indicate that a shift might occur at this level also, but this remains to be confirmed.

Some varieties react more than others to the agronomic selection pressure applied. For example, in the *Phleum* population the proportion of S48 was able to increase during establishment, irrespective of management or fertilizer application, and the dual-purpose nature of this cultivar (3) was borne out. The pasture type S50 and the hay type Bd 2308, on the other hand, responded quickly to changes in management.

When the wide variations in soil, aspect, fertility, frequency and time of defoliation, and other variations in management and climate to which a herbage variety may be subjected are considered, then a certain amount of variation within a herbage grass may well be an advantage. Unfortunately, our knowledge is very limited regarding the ability of cultivars to adapt themselves to various agronomic environments, especially in the physiological sense. On the other hand, competition between different types may eliminate the most useful which might otherwise survive if sown alone. In farm practice the startling ease with which changes occur in grass swards in response to selection pressure, points to the need for a carefully supervised scheme of seed multiplication with the minimum number of generations before the seed reaches the farmer.

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STUDIES IN THE DIGESTIBILITY OF HERBAGE

IX. HERBAGE AND FAECAL NITROGEN AS INDICATORS OF HERBAGE ORGANIC MATTER DIGESTIBILITY

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Data from 291 digestion trials have been used to derive regression equations relating the organic-matter digestibility of herbage to the nitrogen percentage of its dry matter and to the nitrogen percentage in the organic matter of the resulting faeces.

The residual errors are very high and it is shown that the deviations from the lines are not randomly distributed but have a seasonal trend. The seasonal biases have been calculated, and the inclusion of month of cutting as a factor is found to improve the two regressions to some extent. Monthly regressions have also been calculated. Even with these, however, the errors are still too high for many practical purposes.

INTRODUCTION

The factor most often limiting animal production from grass is quantity of useful energy consumed by the ruminant (2). This will be determined by the daily dry-matter consumption and the proportion of that dry matter available as nutrients to the animal; the simplest measure of the latter is the percentage of the herbage dry matter which is digested. Digestion trials are, however, laborious and difficult to conduct on herbage which is rapidly changing in feeding value, unless it is dried or frozen; they can therefore be applied to only a limited numbers of samples. Further, they require larger amounts of herbage than are available in many agronomic and plant-breeding studies. Thus some indirect laboratory method of estimating herbage digestibility (or Starch Equivalent) is necessary.

In 1936, Watson and Horton (15) suggested that the Starch Equivalent of a herbage could be estimated from its crude-protein (N) content. Despite the warning they gave as to the limitations to the use of this relationship, it has since been widely used, without any consideration of the inherent errors, in the design and interpretation of experiments. These errors have two main causes. Thus both Kivimae (3) and Minson and Brown (7) found differences between the equations relating organic-matter digestibility to the nitrogen content of grasses and legumes, while the latter also reported a seasonal bias in these relationships.

In many experiments, digestibility of herbage grazed has been estimated from the nitrogen percentage of faeces, using a regression equation relating digestibility to nitrogen content of faeces (4, 12). The data available, however, indicate that an estimate of digestibility obtained by this method has an error varying from ±2·0 to ±3·7 digestibility units (6).*

METHOD

To study the errors in regression equations relating herbage digestibility to herbage and faecal-nitrogen contents, the data from 291 batches of frozen grass fed to sheep in digestion trials at Hurley have been examined. The herbages were cut from a wide range of simple grass/clover mixtures and pure-grass swards, some of which have been described (9); no data from lucerne or pure clover swards have been included. The cuts were taken at various times between April and November from 1950 to 1959, and were fed in digestion trials as previously described (11). Table 1 shows the number of cuts taken in each month and the ranges in organic-matter digestibility, nitrogen

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*In the case of sub-tropical grasses, Milford (5) found no significant relation between herbage digestibility and faecal-nitrogen concentration.

TABLE 1. Seasonal distribution of herbage cuts

Month of cutting	Number of cuts	Organic-matter digestibility (%)	Nitrogen % in Herbage dry matter	Nitrogen % in Faecal organic matter
Apr.	18	74–85	2·6–4·5	3·8–5·4
May	100	66–85	1·2–4·0	2·1–5·1
June	69	51–81	0·9–3·1	1·4–3·9
July	32	48–79	0·9–3·3	1·3–3·8
Aug.	17	63–81	2·0–4·1	2·3–4·3
Sept.	15	58–80	2·0–4·5	2·5–4·4
Oct.	25	54–82	1·6–4·3	2·0–4·7
Nov.	12	49–82	1·8–5·0	2·1–4·7
Dec.	3	53–55	1·9–2·6	2·5–2·8

Values have been rounded off for ease of presentation in this table

percentages in the herbage dry matter and in the faecal organic matter. Although one would expect slightly better results from using nitrogen percentage in the herbage organic matter, which eliminates the effect of soil contamination, the percentage in herbage dry matter has been used. It is the measure most commonly used.

RESULTS

General regressions

The linear regression relating the organic-matter digestibility ($\mathbf{D}$) of the 291 grasses to the nitrogen percentage of the herbage dry matter (N_H) is given by equation [1] and to the nitrogen percentage in the faeces organic matter (N_F) by equation [2]. The standard error of the estimate* for each equation was also calculated.

$\mathbf{D}=59{\cdot}7 + 5{\cdot}20\ N_H \pm 6{\cdot}17$ ....[1]

$\mathbf{D}=49{\cdot}2 + 7{\cdot}25\ N_F \pm 3{\cdot}99$ ....[2]

The deviations from these two regression equations are not, however, randomly distributed but have a seasonal bias. The differences between the measured digestibilities and those estimated from equations [1] and [2] were calculated for each month: the mean deviations, and the standard errors of these means, are shown in Table 2. (The data for the 3 cuts taken in December have been included in the general regressions, but were not considered when the months were examined separately.)

TABLE 2. Deviations from equations [1] and [2]

Month cutting	Herbage (Equation [1]) Mean deviation	S.E. mean	Faeces (Equation [2]) Mean deviation	S.E. mean
Apr.	2·6	±1·14	−1·3	±0·50
May	4·3	±0·40	1·8	±0·29
June	−0·8	±0·64	1·1	±0·44
July	−3·1	±0·92	−0·4	±0·61
Aug.	−2·0	±0·89	−0·3	±0·58
Sept.	−2·9	±1·29	−1·5	±0·80
Oct.	−4·6	±1·06	−3·1	±0·61
Nov.	−6·9	±2·28	−5·7	±1·64

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*This measures the residual variation about the regression line.

TABLE 3. Monthly regression equations of digestibility on nitrogen content of herbage and faeces

Month	Herbage Equation	Herbage S.E. estimate	Faeces Equation	Faeces S.E. estimate
Apr.	$\mathbf{D}=81{\cdot}8-0{\cdot}35\ N_H$	$\pm3{\cdot}56$	$\mathbf{D}=53{\cdot}3+6{\cdot}05\ N_F$	$\pm2{\cdot}04$
May	$\mathbf{D}=67{\cdot}5+3{\cdot}75\ N_H$	$\pm3{\cdot}96$	$\mathbf{D}=58{\cdot}1+5{\cdot}23\ N_F$	$\pm2{\cdot}49$
June	$\mathbf{D}=54{\cdot}5+7{\cdot}80\ N_H$	$\pm5{\cdot}14$	$\mathbf{D}=45{\cdot}7+9{\cdot}18\ N_F$	$\pm3{\cdot}44$
July	$\mathbf{D}=54{\cdot}6+6{\cdot}19\ N_H$	$\pm5{\cdot}14$	$\mathbf{D}=45{\cdot}6+8{\cdot}54\ N_F$	$\pm3{\cdot}29$
Aug.	$\mathbf{D}=54{\cdot}3+6{\cdot}32\ N_H$	$\pm3{\cdot}62$	$\mathbf{D}=47{\cdot}5+7{\cdot}70\ N_F$	$\pm2{\cdot}40$
Sept.	$\mathbf{D}=56{\cdot}7+5{\cdot}23\ N_H$	$\pm4{\cdot}99$	$\mathbf{D}=37{\cdot}1+10{\cdot}34\ N_F$	$\pm2{\cdot}58$
Oct.	$\mathbf{D}=49{\cdot}8+6{\cdot}90\ N_H$	$\pm5{\cdot}13$	$\mathbf{D}=38{\cdot}7+9{\cdot}38\ N_F$	$\pm2{\cdot}63$
Nov.	$\mathbf{D}=41{\cdot}0+8{\cdot}90\ N_H$	$\pm6{\cdot}49$	$\mathbf{D}=27{\cdot}4+11{\cdot}74\ N_F$	$\pm3{\cdot}24$

Monthly regressions

Seasonal bias is also indicated by the following regression equations based on the data for each month (Table 3 and Figures 1 and 2).

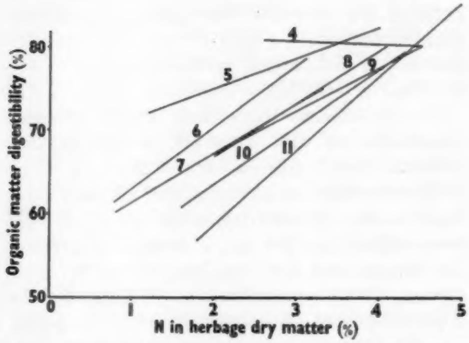

Fig. 1. Monthly regressions of O.M. digestibility herbage nitrogen percentage.

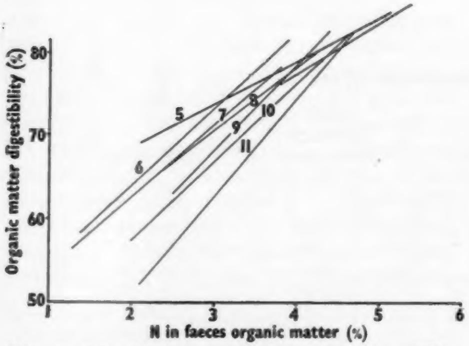

Fig. 2. Monthly regressions of O.M. digestibility faecal nitrogen percentage.

Multiple regressions

A third method adopted has been to calculate regression equations relating digestibility to both nitrogen content and month of cutting.

$\mathbf{D}=69{\cdot}5+6{\cdot}23\ N_H-1{\cdot}88\ M\pm5{\cdot}02$ ......[3]

$\mathbf{D}=56{\cdot}3+7{\cdot}09\ N_F-1{\cdot}00\ M\pm3{\cdot}46$ ......[4]

(M=month of cutting: April =4; December =12)

DISCUSSION

The large errors associated with equations [1] and [2], in which digestibility is correlated with nitrogen content of herbage or faeces, appear to be partly associated with a seasonal trend. By introducing month of cutting (equations [3] and [4]) these errors were reduced by 1·15 and 0·53 digestibility units, respectively. The errors associated with equations [3] and [4] are still too high for most purposes; a somewhat lower standard error of estimate can usually be obtained by the use of the appropriate equation in Table 3. Even if the errors of these equations are sufficiently low for the purpose required, there remains the objection that these monthly equations are based on data obtained under the climatic (especially day-length) conditions obtaining at Hurley; they may not be appropriate under other conditions. It is also worth noting that, for our data, herbage- and faecal-nitrogen values were, in general, quite highly correlated (see also (10)) so that no great advantage was gained by constructing a regression equation based on both herbage- and faecal-nitrogen contents. The correlation appeared to be lowest in the spring.

The application of fertilizer nitrogen increases the nitrogen percentage of herbage, and from a herbage nitrogen regression equation (e.g. [1]) a rise in digestibility would be predicted. However, actual digestibility experiments have shown fertilizer nitrogen to have no significant effect on herbage digestibility: thus the use of an equation from Table 3 may give a quite misleading result in this respect. Fertilizer nitrogen does not, however, appear to have any large effect on the validity of faecal-nitrogen regressions (1, 6).

The relationship between faecal-nitrogen percentage and herbage digestibility, in conjunction with the feeding of known amounts of chromic oxide to estimate faecal output, has been used in a number of experiments to measure the herbage intake of grazing stock. Errors of estimate such as those quoted in Table 3 mean, however, that significant intake differences of less than 25% between swards are unlikely to be detected with any consistency, although much smaller differences in intake have been reported and commented on. Similarly the seasonal effect noted in Table 3 may have been a contributing factor in results such as those (14), where a seasonal fall in the nutritive value of digestible nutrients was reported (see also (1)). The similarity between the herbage and faecal deviations shown in Table 2, the correlations between herbage- and faecal-nitrogen percentages, and the similarity between Figures 1 and 2, all suggest that the biases in the faecal-nitrogen regressions are due to the same causes as the biases in the herbage-nitrogen regressions, which clearly arise because the relationship between herbage digestibility and herbage-nitrogen content is associative rather than causative. In other words, herbage-nitrogen content does not appear to be the main factor controlling herbage digestibility.

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ABSTRACTS

SOCIETY OF CHEMICAL INDUSTRY. **Monograph No. 9. Chemical aspects of the production and use of grass.** 1960, pp. 228, bibl. at end of papers, 14×22 cm., London: Soc. Chem. Ind., 14 Belgrave Sq., S.W.1.

This work comprises papers (with discussions) read at a symposium (organized by the Dublin and District Section of the Agricultural Group) held in Dublin, 15–18 Sept., 1959. The following were among the papers presented: The use of fertilizers on grassland, by G. W. Cooke; Manuring and conservation with intensive grassland, by J. A. Collier; Conditions in which nitrogen fertilizers may be used in pastures without affecting the health of the animals, by A. Voisin; Utilization of ground rock phosphate by different species of pasture plants, by M. Neenan: Effects of fertilizer treatments and cutting managements on yield and quality of grass and clover swards, by M. E. Castle and D. Reid; Effect of organic and inorganic nitrogenous compounds on yield, chemical composition and botanical constitution of grass swards, by S. McConaghy and others; Legumes and herbage production, by T. W. Walker; Response of grass-clover mixtures to lime and sulphate of ammonia, by P. Bergin; Chemistry of silage-making, by W. S. Ferguson; Effect of growth-regulating weedkillers on the botanical composition and productivity of permanent grassland, by R. S. L. Jeater; The mineral composition of pasture in relation to animal health and production, by L. B. O'Moore; Measurement of the quantities of herbage consumed by grazing animals, by J. L. Corbett and J. F. D. Greenhalgh; Herbage composition and nutritive value, by W. F. Raymond and others.—M.H. From *Herbage Abstracts.*

EDDOWES, M. **Maize as a silage crop.** *Tech. Bull. 3 Harper Adams agric. Coll.* 1960, pp. 14, bibl. 4, 3*s*. 6*d*.

An account is given of growing maize for silage on a commercial scale on the College Farm in the English West Midlands during the contrasting seasons of 1959 and 1960. Yields of green matter ranged from 20–25 tons in 1959 to 25–31 tons per acre in 1960. In both years the yield of dry matter was from 4 to over 5 tons per acre. Maize should be sown as early as possible (at the end of April to the beginning of May) at a seed rate of 30–35 lb./acre to give a population of some 40,000 plants per acre. Harvesting should be delayed, consistent with the avoidance of severe frosts, until the end of September or beginning of October to obtain maximum nutritive value. Pre-emergence and post-emergence weedkillers gave adequate weed control. 2,4-D amine applied at 1 lb. acid equivalent per acre, at the 4-leaf stage, when the crop is 4–5 in. high should normally give satisfactory control, at low cost. The more expensive simazine gave excellent control of annual weeds in both years at a rate of 2 lb. 50% W.P./acre, and should be especially valuable in moist soils, in the western half of the country, and against annual species resistant to 2,4-D. Rooks and other birds, are major pests. 8–10 cwt. of a high nitrogen C.C.F. fertilizer should be applied and worked into the seed-bed. A chopper-type harvester, fitted with an attachment to guide the maize stalks into a cutting cylinder, is necessary for efficient and clean handling of the crop. A standard flail-type machine will harvest the crop, but great care is needed to avoid contamination of the lacerated material by soil. The estimated cost of growing and ensiling the crop was £35 per acre (including £5 rent) or about £2 per ton of silage. On lowland farms maize should be greatly superior as a fodder crop to mangels and arable silage. On larger farms, and where conditions are unsuited to grazing, it has a higher potential value than kale. It can be a useful complement to grass, to intensify output, and could replace short leys on arable land.—A.G.G. Hill. From *Herbage Abstracts.*

BOOK REVIEWS

WHYTE, R. O. **Crop production and environment.** 1959, pp. 392, illus., 22×14 cm., London: Faber and Faber, 63*s*.

A noteworthy development in plant biology during the past decade has been the great awakening of interest in the plant as an organism. Concurrently with the continued exploration of the physiology of processes in cells and tissues, many workers are now attempting to evaluate the relative significance of the different physiological processes during growth, to examine the quantitative aspects of the growth of whole plants and of organs, and to investigate the environment and its interactions with plants growing therein. The whole of this field is beyond the scope of a single treatise and Dr. Whyte, although he touches on many more aspects in this completely rewritten edition than in the first edition (*Herb. Abstr.* 17: 871), has selected from it those aspects concerned primarily with the change from the vegetative to the flowering state. Within this context, the volume is a valuable guide to the published work on the physiological mechanisms involved and the differing responses of a wide range of crops, but, because of it, a very narrow viewpoint of the problems of crop production in relation to the environment is presented. Dr. Whyte is well aware of this and has appended in the text guides to the wider quantitative issues. The reader can therefore find this way quickly to recent contributions on subjects such as the leaf-area index (but not net assimilation rates), tillering in grasses, competition for light (but not nutrients), tuberization in the potato, and equipment for growing plants in controlled environments. For a book with this title, the discussion of the natural environment is disappointing. This is confined to the reproduction, without textual comment of isopleths of incoming radiation in January and July, two uncited references to temperatures within a crop, two references to climatological approaches without discussion or warranted criticism, and a graph of the variation in daylength with season for latitudes 42°–62°N. The book is primarily directed to the agricultural botanist in the widest sense. In the author's words, it "represents a report of a shadow conference at which the sayings and writings of specialists in this subject from different countries are presented, as nearly as possible in their own words. The result is a picture . . . unavoidably still somewhat shapeless and untidy". This approach to the subject is extremely fair to the authorities cited although it leads to many unresolved conflicts of opinions. Consequently, the novice may be somewhat bewildered by the form, composition and texture of the picture but the connoisseur will find much of interest which will exercise his talents of judgement, taste and discrimination.—F. L. MILTHORPE. From *Herbage Abstracts*.

IVINS, J. D. [Editor]. **The measurement of grassland productivity.** 1959, pp. viii + 217, bibls. at end of chaps, illus., London: Butterworths Sci. Publ. 35*s*.

The realization of the full potential value of grasslands as a source of livestock products is comparatively recent and still possibly not generally appreciated. Although new varieties of herbage plants have been produced and new techniques developed which have resulted in vast increases in the production from grasslands, a constant hindrance to progress is the lack of confidence in the variety of methods which can be used to measure and compare pasture productivity under different conditions and treatments.

Unlike most arable crops, grass is a most difficult crop to measure, for its produce is grown to feed livestock and consequently its ultimate value rests on its effects on animal production. At the same time the normal grazed sward consists of a mixture of plants—grasses, clovers and herbs, each species of which makes a particular demand upon its environment. The Sixth (1959) Easter School in Agricultural Science, at which the following papers were presented, was primarily concerned with the techniques available for such measurements: The evolution of grassland research techniques, by Dr. William Davies; Twenty years of grassland recording on the experimental farm at Rengen, by Professor E. Klapp; The ley in relation to crop productivity, by T. E. Williams; The preliminary classification of herbage varieties, by R. P. Hawkins; Varietal characteristics of herbage plants in relation to their agronomic assessment, by Ll. I. Jones; Analysis of the distribution of foliage area in grassland, by Dr. J. Warren Wilson; The measurement of herbage production, by J. O. Green; The value of herbage estimates in animal production experiments, by C. Line; Experiences in the measurement of herbage consumption by livestock, by J. Davison; A review of herbage production and consumption yield measurement techniques adopted in N. Ireland, by J. Lowe; Pasture experiments with animals, by F. E. Alder; The relationship between grazing intake and animal production, by Professor W. Holmes; Studies of herbage production and consumption and the production of dairy cows in various grazing conditions, by Dr. D. S. MacLusky; A critical review of pasture evaluation via the Falke-Geith Method, by Dr. P. Boeker; The interpretation of animal production data in grassland evaluation, by Professor J. D. Ivins; The nutritive value of herbage, by W. F. Raymond; Ruakura experiences with the chromium-faeces nitrogen method, by Dr. R. J. Lancaster; The digestibility of herbage by dairy cows, by J. Davison; The measurement of grassland productivity on dairy farms in England and Wales, by J. Clark; Sixteen years experience of grassland recording on a farm scale, by Rex Paterson.

VOISIN, A. Better grassland sward. [English edition] 1960, pp. xiv + 341, bibl. 286, 22·5 × 14·5 cm., London: Crosby Lockwood & Son Ltd., 42*s*.

In this book André Voisin has set out to illustrate the dynamic nature of the flora of the grassland sward and of the micro-fauna and flora of the grassland soil, which constantly changes in response to changes in the environment. He has dealt extensively with the influence of those factors of the environment which are within the control of the farmer: grazing or cutting, fertilizer practice, the correction of trace-element deficiencies, cultural operation, including ploughing and reseeding, and seeds mixtures. He has drawn extensively from the literature to illustrate the typical changes that occur with variation in these factors. After reading this section anyone who has to manage grassland should have no doubt but that the floristic composition of a grassland sward is very largely a reflection of the management. The dynamic nature of the grassland sward is clearly established but one might criticize the fact that there is little helpful indication of the specific changes that take place in a sward that is progressively improving under improved grassland management practices.

The ploughing and reseeding of permanent pastures as a means of increasing the productivity of grassland is strongly deprecated. Evidence is produced to show that the high yields in the initial years after ploughing are obtained at the expense of profligate decomposition and depletion of soil humus. Evidence is quoted to show that ploughing impoverishes soil micro-flora and fauna and is followed by a deterioration in soil structure. This complex of changes brings years of reduced yields that only increase with the recovery of soil conditions. These 'years of depression' are considered to be the inevitable consequence of ploughing and reseeding as a means of grassland improvement. Perhaps less than justice is given to the efforts of plant breeders in producing varieties that are truly persistent under grazing. It may well be that the swards which supplied the evidence of marked depression in yields of recently sown pastures had not been established from varieties of grass of proven persistence under grazing. This section leads to an engaging disquisition on the role of earthworms in developing fertile grassland soils, culminating in the correlation between the distribution of earthworms and Wegener's theory of continental drift. He sees the earthworm as a creator of civilizations.

The controversial element in this book is the place and efficacy of ploughing and reseeding as a means of improving grassland productivity. This is an old controversy and it should not overshadow the other and main theme that the grassland sward (ley or permanent) is a product of its environment and that this environment can be changed by proper deployment of fertilizers, trace elements and, particularly, grazing and cutting managements so as vastly to increase production from permanent grassland without recourse of ploughing. The failure of ploughing and reseeding, as evidenced by static or increasing area of permanent grass, is not conclusive evidence that as a means to an end the practice is doomed to failure. No one would wish to instance the large area of poorly fertilized and badly managed grassland as evidence that the means advocated for improvement are inherently incorrect.

The book abounds with reference to relevant scientific and technical literature, quotations and tabular data. While the reader is conscious that the text has been translated from the French this has been faithfully done and preserves the personality and directness of the author.—T. E. WILLIAMS.

MOORE, I. Winter keep on the farm. 1960, pp. viii + 86, illus., 19×12 cm., London: Farmer and Stockbreeder Publ. Ltd., 9*s*. 6*d*.

This book is the most recent of several which have been written by Professor Ian Moore on practical aspects of farming in Great Britain. The greater part of it is devoted to a detailed consideration of the economics, production and utilization of kale. The author attaches great importance to the value of this crop in winter-feeding programmes and draws on considerable practical experience and experimental data to support his views. Other crops for winter-feed, including cabbage, rape, swedes, turnips, mangels, fodderbeet and kohl-rabi, are also discussed, but in less detail, as are the use of cereals (including rye) and Italian ryegrass for early spring grazing. There is, however, no specific reference to the production of foggage, which is now an accepted form of winter-keep in this country. The book is easy to read and understand. It contains much useful and up-to-date information and should be of sound practical value to farmers and agricultural students.—J. E. RUDMAN. From *Herbage Abstracts*.

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3. Each article should begin with an adequate summary which should state briefly: what was done, why it was done, the results obtained and the conclusions drawn. The introduction to the article, which follows the summary, should briefly explain the nature of the problem dealt with and the experimental methods used to attack it. The presentation of experimental data must be concise and their statistical significance indicated, where possible. There should follow a clear statement on the application of the results obtained and/or their relationship to some problem of grassland- or animal-husbandry. Tables, graphs and diagrams should be as few and as simple as possible and must be confined to essential data. Numerical results should be presented either as tables or diagrams, not as both.

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